Naval Fuels & Lubricants
Cross Functional Team
Research Report

DEVELOPMENT OF A NEW SPECIFICATION FOR AIRCRAFT CATAPULT LUBRICANT, LA7, NSN 9150-01-430-2884

NF&LCFT REPORT 441/13-009

30 September 2013

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The goal of this program was to develop a replacement specification for the LA7 aircraft catapult launch system lubricant that would provide adequate performance and be readily obtainable in bulk quantities by the procurement community.

The approach followed in this program was based upon a review of lubrication needs of the catapult systems, the fact the systems have traditionally used qualified aviation piston engine oils (APEO's) and that current APEO's are providing acceptable performance. Samples of current APEO's were obtained from the three primary APEO producers (Shell, ExxonMobil and ConocoPhillips) and subjected to a series of standardized, readily available performance tests with the goal of developing a specification which would facilitate procurement of a satisfactory product in bulk.

Analysis of the data collected in this program lead to the development of a proposed set of tests and limits for a Commercial Item Description specification. The tests are all readily available from commercial labs thereby facilitating the procurement of an acceptable product based upon batch/lot quality assurance testing.

LIST OF ACRONYMS/ABBREVIATIONS

Aviation Piston Engine Oil...APEO

Commercial Item Description .... CID

DLA Energy Product Code for SAE J1966 Grade 50 Lubricant LA7

DEVELOPMENT OF A NEW SPECIFICATION FOR AIRCRAFT CATAPULT LUBRICANT, LA7, NSN 9150-01-430-2884

1.0 BACKGROUND

The steam driven shipboard aircraft catapult systems have traditionally used qualified aviation piston engine oils (APEO's) to lubricate critical parts. The catapult launch systems first used products meeting the old military specifications MIL-L-6082 (non-dispersant oil) Grade 1100, or MIL-L-22851 (ashless dispersant oil) Type IIa or IIb. In 1995 the military specifications were canceled and replaced with the commercial SAE Standards (J-Spec's), J1966, reference (a) and J1899, reference (b) with products corresponding to SAE Grades 50 or 60 respectively. Currently, the catapults continue to operate satisfactorily using the J-Spec oils and therefore the properties and performance characteristics contained in the J-Spec's are adequate. Unfortunately, these APEO's are quickly becoming specialty products and are no longer available in bulk quantities which is how they are primarily used in the catapult launch systems. The large quantity of LA7 (the DLA Energy Product Code for SAE J1966 Grade 50 Lubricant) that is needed to fill up the tanks on an aircraft carrier after a yard period preclude the use of drum quantities of APEO's. As a result Defense Logistics Agency – Energy (DLA-E) agreed to provide funding for a project to develop a new lubricant specification to address the shipboard aircraft catapult application.

2.0 OBJECTIVE

The goal of this program was to develop a replacement specification for the LA7 aircraft catapult launch system lubricant that would provide adequate performance and be readily obtainable in bulk quantities by the procurement community.

3.0 APPROACH

3.1 Supplier Participation

Catapult oils have always been qualified aviation piston engine oils (APEO's). The catapult launch systems first used products meeting the old military specifications MIL-L-6082 (non-dispersant oil) Grade 1100, or MIL-L-22851 (ashless dispersant oil) Type IIa or IIb. In 1995 the military specifications were canceled and replaced with the commercial Society of Automotive Engineers (SAE) Standards J1966 and J1899 (J-Specs) with products corresponding to SAE Grades 50 or 60 respectively.

For this project, a new performance-based standard was to be developed with requirements based on the fundamental properties of the aviation piston engine oils currently being used, but containing specific requirements for catapult applications. The three primary APEO producers (Shell, ExxonMobil and ConocoPhillips) reviewed the test plan and participated in the evaluation.

3.2 Test Samples.

Testing was performed on currently qualified SAE J1966 and J1899 lubricants conforming to SAE Grades 30, 50 and 60 for each Standard. In addition, J1899 multigrade products (e.g. SAE Grade 15W50) and J1899 SAE Grade 50 oils containing anti-wear additives were tested. A MIL-PRF-6081 Grade 1010 product was included as a low-viscosity reference oil. A sample of LA7 oil from a (ground based) operational catapult was also included in the base line testing. A total of 18 individual oil samples are were evaluated.

By design, not all samples were evaluated in every test identified.

Case quantity samples were provided from the three qualified suppliers at no cost to the program. The samples were from commercial batches of APEO's and provided a range of sulfur contents. Since sulfur can act as a natural antioxidant and/or provide anti-wear properties, an assessment the sulfur value was included in the analysis of performance. Normal manufacturer's batch quality conformance data was also provided for each sample.

3.3 Test Program Administration.

Test samples were sent to the AIR-4.4 test laboratory at Patuxent River, MD. NAVAIR prepared Purchase Requests Forms and Contracts as required to conduct the specified tests at a contract laboratory. The test samples were coded and shipped to the successful contract bidder, Intertek Laboratories Inc., located in San Antonio, TX.

3.4 Evaluation of Performance Properties.

While current performance is adequate, the APEO J-Spec's also include requirements for laboratory bench, ground and aircraft flight tests using spark-ignition combustion engines for product qualification. These engine tests, while necessary to evaluate the performance of APEO's for their expected long-life in continuous use recirculating-flow oil systems, may be excessive for the single pass lube system design of the catapult launch system. While the need for the full size aircraft engine and flight test requirements could be waived for the catapult application, reliance on the laboratory engine test is essential to determine a host of oil properties which are also important to the catapult application (i.e. anti-wear, oxidation, thermal stability, corrosivity, cleanliness). The laboratory engine test used, ASTM D-6709 Sequence VIII single cylinder engine test, reference (c) is frequently unavailable and its future as a viable method is in doubt. To obtain similar performance data for catapult oils, replacement tests will be needed. Industry standard test methods for assessing oxidative and anti-wear properties were identified and a range of qualified J-Spec oils tested in the effort to determine method suitability and pass-fail criteria.

- Oxidative Stability

A primary requirement in the program was to determine a suitable test to assess the oxidative properties of the existing oils used. From that point, new requirement(s) were to be established for laboratory (glassware) tests to examine oxidation and thermal stability (or one combination test for both) to replace that assessment previous supplied by the Sequence VIII engine test (as measured by the oils post-test viscosity and total acid number changes recorded in that test). Duplicate tests were run on selected SAE Grade 50 and 60 samples to determine test suitability. Typically, oxidation tests are used to assess the long term stability of products intended for continuous use in circulating oil systems. Tests can be run at accelerated conditions or at normal operating temperatures and can be of short or extended durations. For the catapult application the intended assessment is to validate the oil has adequate oxidation features to prevent: excessive oil degradation; the formation of harmful (corrosive) by-products; and potentially harmful gums, sludges or other types of oil deposits. Representative oxidation / corrosion and oxidation stability data was generated on typical J-Spec oils to determine current performance. Several different test methods and test temperatures were investigated to determine the most appropriate parameters for this application. Since oxidation resistance is not the primary concern for the catapult oils only selected oil samples were examined. The candidate methods selected and the number of samples examined in each were:

a. FTM Method 5308 (Corrosion and Oxidative Stability), reference (d) / ASTM D4636 (Procedure 2), reference (e). This combination test examines both oil degradation and resulting corrosivity and sludge formation. The 72 hour test is run at a specified temperature and assesses the degradation of the lubricant as measured by the post-test change in the product’s viscosity and Total Acid Number. In addition, the corrosive attack of commonly used metals is determined by the weight change of five metal specimens immersed in the oil. Typically, the test is run at two or three different temperatures to provide a performance profile of the product at several stress levels.

- Eight oils tested at three temperatures each (160ºC, 170ºC and 180ºC), each in duplicate (48 tests)

b. ASTM D943 (Oxidation Characteristics of Inhibited Mineral Oils), reference (f). This is a very long duration test, typically 2000 hours, run at 95C in the presence of water and an iron-copper catalyst. It is mainly used to assess oils used in circulating oil systems. The test is terminated when the total acid number change reaches a value of 2.0 mg KOH/g and the number of test hours are then reported as the “oxidation lifetime”.

- Five oils in duplicate (10 tests)

c. ASTM D2272 (Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel), reference (g). This method uses an oxygen-pressure vessel to evaluate the oxidation stability of new and in-service turbine oils having the same composition (base stock and additives) in the presence of water and a copper catalyst coil at 150ºC. The number of minutes

required to reach a specific drop in gage pressure is reported as the oxidation stability of the sample.

- Nine oils in duplicate (18 tests)

- Wear Performance

The engine test requirements of the J-Specs are not directly applicable to these catapult oils. However, the Sequence VIII test does provide information regarding the anti-wear properties and deposit-forming tendencies of APEO's. The primary wear mode expected in the catapult application would be due to high sliding contact of the piston in the cylinder during launch. Subsequent oil deposit formation would be a consequence of the frictional heat generated at that contact during operation. Hence, the primary focus was on wear tests employing high sliding contact with an indirect assessment of deposition from the visual condition of the test specimens involved. Since anti-wear performance is considered a key requirement of the catapult oils, the evaluation assessed the anti-wear properties of the full range of qualified J-Spec oils in addition to a low-viscosity reference oil in an effort to establish pass-fail criteria. Initial wear testing consisted of evaluating all products (in triplicate) in tests having high-sliding contact conditions. Selected products were further evaluated using the more complex contact conditions of the ASTM D5182 FZG gear test, reference (h). The testing proceeded as follows:

a. ASTM D4172 four-ball wear test, reference (i).

   - 16 oils in triplicate (48 tests)

b. ASTM D2783 four-ball EP testing, reference (j).

   - 16 oils in triplicate (48 tests)

c. ASTM D5182 Evaluating the Scuff Load Capacity of Oils (FZG method).

   - 8 oils in duplicate (4 assessments per oil, gear side A and B = 32 tests)

- Basic Property Tests.

The normal quality assurance test data required in the SAE J1966 and J1899 Standards was reported for each APEO sample examined.

Data was analyzed continuously as it was being developed. Confirmation re-testing was performed when unusual results were obtained.

3.5 Reporting.

Monthly progress reports were provided to the DLA-E point-of-contact. This final report is hereby submitted at the conclusion of the test program and includes the following:

- all the test data results
- discussion of data analysis
- conclusions and recommendations.

4.0 PROGRAM TEST RESULTS AND DISCUSSION

All of the required contract testing has been completed at the Intertek laboratory. In general, the test results obtained were reasonably repeatable. On initial review of the results some isolated data anomalies in some of the test sets were noted. However, there were serious discrepancies with the entire set of the ASTM D4636 oxidation test data. As reported in Progress Report #13 Intertek was contacted regarding the observed problems and requested to comment (see Appendix A). A telephone discussion with Intertek personnel regarding the questionable data was held on 20 May 2013. While the minor problems with the D4172 Four-Ball Wear Test were successfully addressed there was no resolution regarding the discrepant D4636 values. All the data received is being reported herein and discrepancies, or suspected outlier points, will be identified for each test set.

The test lubricants were supplied by three major aviation piston engine oil manufacturers and are identified throughout the report as company “A”, “B” or “C”. The specific products are further identified first by their respective SAE Standard number, J1966 or J1899, followed by their SAE Grade identification, -30, -50, -60 and –MG (Multigrade). An additional marking of -50+ is used to identify products that contain a specific anti-wear additive (tricresylphosphate –TCP) mandated by the Federal Aviation Administration for use in certain aircraft engines. Two Navy supplied samples are also included in the evaluation and are identified with an “N” as the manufacturer. One sample was obtained from the supplies used at the Patuxent River test catapult facility and is a J1966 Grade 50 oil (sample N J1966-50). This sample has the same commercial brand name as sample A J1966-50, but is from a different production batch. The other Navy sample is a MIL-PRF-6081 Grade 1010, low viscosity, mineral based, oil used as a reference (sample N Gr.1010).

4.1 Physical and Chemical Properties.

The typical quality assurance type properties used to validate product conformity to the specific SAE Standard were reported by the manufacturer for each lubricant supplied. The Navy Fuels and Lubricants laboratory at Patuxent River independently measured the same properties for confirmation. The test data from both sources complies with the specification requirements and is shown in the Table of Physical and Chemical Properties Data, page B-12 of Appendix B. The data recorded mainly consist of the physical properties of each sample such as: viscosity, viscosity index, API gravity, sediment content and ash content. Two chemical properties were also measured: the sulfur content and total acid number. The API gravity and the sulfur content of the product are the key properties used to identify the base oil consistency (crude source and processing) and are required by the SAE J1966 and J1899 specifications to remain within certain bounds in order to remain qualified.

These quality assurance-type physical and chemical property tests indicate that the products conform to their initially qualified profile: they are of the proper viscosity grade, are free of contaminants and have the prescribed Sulfur and API gravity for their respective Qualification Reference Number. Therefore, no formulation change is apparent and they should perform as intended. The laboratory examination did not include any test measurements to confirm satisfactory performance such as the Sequence VIII engine test.

4.2 Evaluation of Oxidation Performance Properties.

Three different standard ASTM oxidation tests were selected as previously described in paragraph 2.4. Two of the test methods, D943 and D2272 are used to evaluate steam turbine lubricants, while the third, D4636 is used for gas turbine engine oils. While steam turbines and launch catapults are both steam driven, the lubrication requirements of each are significantly different. The steam turbines have recirculating oil systems for long-term operation while the catapults are a one-pass and gone scheme. Oil oxidation is a function of both time and temperature and the presence of water will accelerate the reaction. The steam turbine oils are formulated to handle the expected ingress of moisture in the lube system for extended durations without suffering excessive degradation while the aviation J-Spec oils are not. Although exposed to large volume of steam for each launch the time of lubricant exposure is very short and the oil is unlikely to significantly deteriorate during use. The tubes are again lubricated when the shuttle is slowly returned back to the launch point. Residual oil on the surfaces at that point will be exposed to the hot, steamy environment until the next launch. Therefore, the effect of steam on the oxidative capability of the J-Spec aviation oils was unknown and in need of investigation. This was done using both the long term D943 test and the short term D2272 test.

4.2.1 ASTM D943 - Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils.

When used to assess steam turbine oil this test typically runs a minimum of 2000 hours. It is run at 95ºC in the presence of water and an iron-copper catalyst and is terminated when the total acid number reaches a value of 2.0 mg KOH/g with the number of test hours at that point reported as the “oxidation lifetime”. The tests were run with duplicate samples of each of five products. Three manufacturers and a Navy sample were evaluated. In general products from company A performed the best with company B coming in second. The Navy sample was in between A and B. Only one sample of company C product was able to complete the 1000 hour mark in three attempts. Two subsequent tests were terminated at the 668 hour mark with TAN values exceeding the 2.0mgKOH/g maximum limit. (Figure 1)

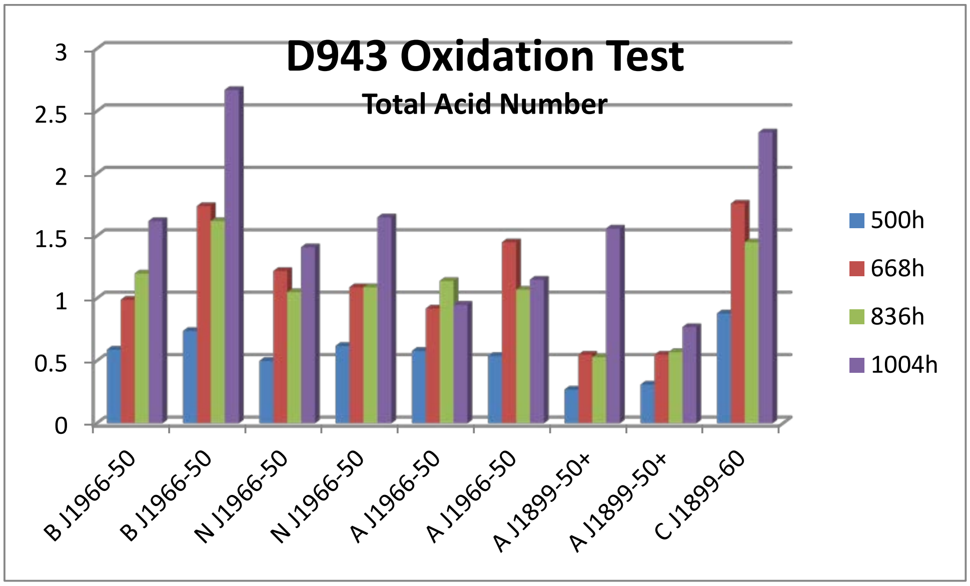

Figure 1. ASTM D943 Oxidation Test Results – Total Acid Number

The values obtained are relatively low oxidation lifetime values compared to the performance of steam turbine oil products which have minimum values of 2000 hours and usually many more. When considering that the products tested are aviation oils not intended to handle large volumes of moisture in operation the products actually performed fairly well.

Due to unexpected contractual restraints on incremental funding for progressive time blocks, testing of all samples was terminated at 1000 hours. However, the testing completed was sufficient to show the five products were basically equivalent in performance. With the exception of sample A J1899-50+ all products deteriorated at about the same initial rate and two of the samples had already exceeded the maximum 2.0 TAN level at the 1000 hour point. The two A J1899-50+ samples displayed a lower initial rate of deterioration but one produced a large spike in TAN value at the 1000 hour mark, which from the trend indications of the other samples, suggested that it too was nearing its oxidation lifetime. Since the tests were not all run-out to their final TAN end point the normal oxidation lifetime (in hours) could not be calculated. However, from the repeatability of the test method, it would appear that all of the products are in the same class of performance.

4.2.2 ASTM D2272 – Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel.

This method uses an oxygen-pressure vessel to evaluate the oxidation stability of new and in-service turbine oils in the presence of water and a copper catalyst coil at 150ºC. The number of minutes required to reach a specific drop in gage pressure is reported as the oxidation stability of the sample. The higher the minute value the better the indicated oxidative resistance. The use of oxygen, pressure and elevated temperature greatly increases test severity and D2272 is often used as a batch acceptance test for products that were originally approved using the longer-term D943 test. This test was selected because of its short term duration and reported association with the long term D943 test results. Due to the much shorter test duration (and lower cost) a total of

nine products were examined; four new products in addition to the same five oils examined in the D943 oxidation test. The new products added were the Navy's low viscosity reference oil N Gr. 1010 and three J1899 multi-grade oils. Of these multi-grade oils, one was a completely mineral oil based product, while the other two were a blend of polyalphaolefins (PAO) and mineral oil. The two PAO based products also include more advanced additive technologies (i.e. dispersants, anti-wear, viscosity index improvers, etc.) while the mineral based oil has an older generation viscosity index improver in combination with a typical single grade J1899 type additive system. Four tests were run on each oil (Figure 2).

The results from the straight mineral oil based samples compare well to those obtained from the D943 testing and suggest that all the products are of the same performance class. The results on the two PAO based multi-grade oils show a significant improvement in oxidative performance over the conventional mineral oil based products. The complete test results are reported in the D2272 Table of Appendix B and are illustrated in the graph below.

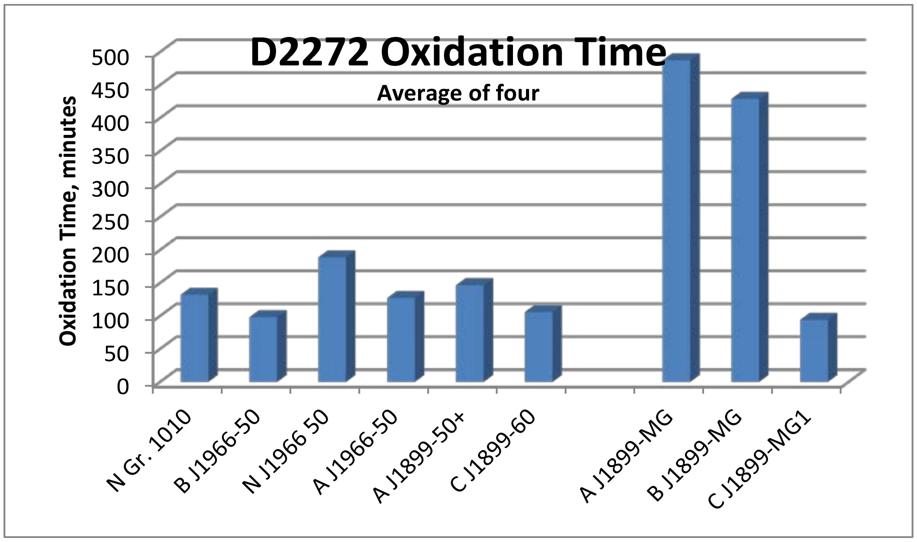

Figure 2. ASTM D2272 Oxidation Time

4.2.3 ASTM D4636 Standard Test Method for Corrosiveness and Oxidation Stability of Hydraulic Oils, Aircraft Turbine Engine Lubricants and Other Highly Refined Oils (Procedure 2).

This combination test examines both oil degradation and resulting corrosivity of metal coupons and sludge formation. The 72 hour test is run at a specified temperature and assesses the degradation of the lubricant as measured by the post-test change in the product's viscosity and Total Acid Number. In addition, the corrosive attack of commonly used metals is determined by the weight change of five metal specimens immersed in the oil. The test series was run at three different temperatures, 160ºC, 170ºC and 180ºC to provide a performance profile of each product at several stress levels. Eight oils were run in duplicate at each temperature. These were the same five single grade oils run in the D943 and D2272 oxidation tests along with the three multigrade products. The Navy low viscosity reference oil was not examined.

Compilation of the contractors' ASTM D4636 oxidation test series data revealed significant discrepancies and the test laboratory was contacted regarding the Navy's observations. A copy of the Memo Report identifying the specific discrepancies noted is included as Appendix A. This test series was intended to create an "oxidation performance map" by running each test oil at three temperature steps, each ten degrees Celsius higher than the previous, and plotting the resulting oil degradation (as evidenced by changes in viscosity and Total Acid Number). During the method development tests, run on one J1966 oil and one J1899 oil, this test series produced smooth graphs showing increasing oil degradation for each product at each of the four temperature steps used (Figure 3). Plotting the results of the contract tests produced undecipherable graphs with the data randomly increasing or decreasing as the test temperature increased (Figure 4). The contract lab data also produced viscosity and TAN changes that were substantially lower in magnitude than those experienced in the development tests run at the same temperatures. The apparently erratic results are of particular concern considering that the J1899 oil was run in both the Navy development tests and in the contract testing, however, different batches of the same product were used. The single operational difference noted between the tests

run was that the contract lab used a Cadmium metal coupon in its metal package, while the Navy used a Silver coupon, with the other four metal coupons being the same for each lab. It is doubtful if the use of the Cadmium coupon alone can explain the erratic results obtained.

The contractor data is listed in the D4636 Table of Appendix B, and is unusable for this project. The below graphs illustrate the different oxidation performance profiles produced. The first graph shows the results of the initial development testing while the second graph shows the results from the contracted effort. Both graphs use the post-test percent change in viscosity at 40ºC as the performance indicator. The method development data is provided in Appendix A.

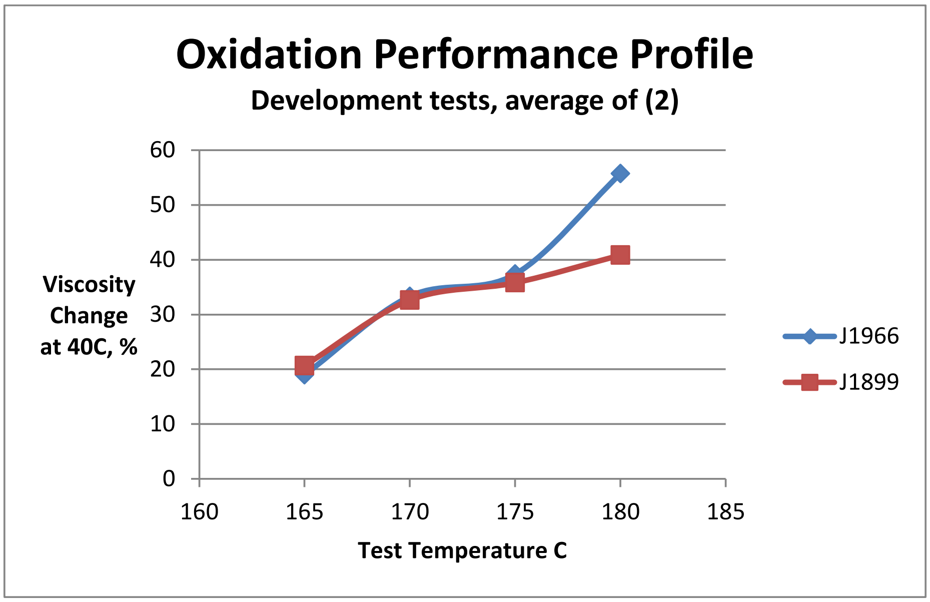

Figure 3. Oxidation Performance Profile – Viscosity Change % at 40ºC

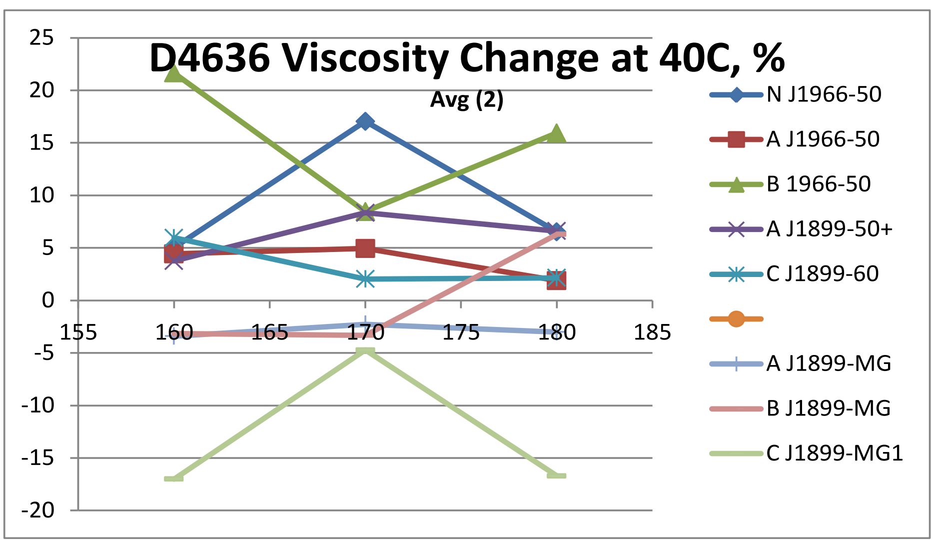

Figure 4. ASTM D4636 Viscosity Change at 40ºC, %

As can be seen in the graphs there is no similarity in oxidative performance indicated by the contractor data when compared to that developed during the Navy development test series. The teleconference with Intertek personnel on 20 May reviewed their laboratory's D4636 test operation and procedures in detail. We were assured that all the testing was performed in accordance with the procedures specified in the ASTM method. The lab's test sample number identification and validation processes were verified to satisfy our concerns that the test sample data may have possibly been mixed when reported. Those test control parameters which are known to most directly affect oxidative performance, e.g., airflow, test tube block temperature, condenser temperature and operating time, were described and discussed. The only item having even minor uncertainty in the discussion was in regard to the temperature of the water going to the condenser. Extremely wide variations in condenser water temperature can lead to different results when testing a specific product. However, review of the data showed numerous examples of widely different results obtained on the same oil product while being run in duplicate in the adjacent test chamber. The conclusion was that there were no evident factors to explain why the D4636 test results were erratic. Unfortunately, the data reported is not useful for this evaluation.

4.3 Evaluation of Anti-wear Performance Properties.

Due to its design the primary wear mode expected in the catapult application would be due to high sliding contact of the piston in the cylinder during launch. Subsequent oil deposit formation could also be a consequence of the frictional heat generated at that contact during operation. Hence, the primary focus in this phase was on wear tests employing high sliding contact with an indirect assessment of deposition from the visual condition of the test specimens involved where possible. Since anti-wear performance is considered a key requirement of the catapult oils the evaluation assessed the anti-wear properties of the full viscosity range of qualified J-Spec oils in addition to one low-viscosity reference oil. In these first two test series products conforming to both SAE J1966 and J1899 with viscosity Grades 30, 50, 60 and three multigrade products were evaluated. The 16 oils in this initial group were run in two standard ASTM tests both of which employ simple geometry specimens, are of short duration and low cost. D4172 and D2783 are both four-ball tests used to measure either the wear characteristics or the extreme pressure properties, respectively, of test oils. In combination these two tests series would provide a general indication of the range of anti-wear performance to be expected when using J1966 or J1899 oils of any viscosity grade and formulation. Since the catapults traditionally operate using only the higher single viscosity grade products, additional wear testing using a more complex (and expensive) apparatus was employed using a reduced field of eight products consisting of SAE 50, 60 and multigrade lubricants. The D5182 FZG gear test was an attempt to quantify potential differences in the scuffing resistance of these typically used catapult oil products. The combined intent of these test series was to assess whether any of these data would then be useful to establish possible pass/fail anti-wear criteria for lubricants intended for catapult applications.

4.3.1 ASTM D4172 Standard Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method).

This test operates at the standard conditions of 1200 rpm for 60 minutes at 75ºC with a load of 40Kg. The resulting velocity of the four ball configuration is 9.05 inches per second at the three points of contact. At the conclusion of the test the wear scar on each of the three stationary balls is measured in two dimensions; first in the direction of rotation, and the second at 90 degrees from that. The average value of the six measurements is then reported as the wear for that test run. Lower wear-scar diameters are indicative of better anti-wear performance than higher wear-scar diameters. The test data is provided in the D4172 Table of Appendix B along with supplemental graphs.

As previously noted Intertek was contacted regarding four data points initially reported that were apparent statistical outliers and provided repeat runs for those items. The data reported herein has deleted the suspect data and replaced them with the new results. Graphically the data is summarized below arranged in order of increasing viscosity for the single grade products with the multigrade products displayed at the end. (Figure 5) It should be noted that while the repeated tests did improve the consistency of the results somewhat, the values obtained were still outside of the repeatability of the method for three of the four samples re-examined (as highlighted in the D4172 Tab). However, since there was such a long delay between the testing dates the new data may be more representative of the tests' reproducibility than of its repeatability. As such the results then fall within the precision of the method.

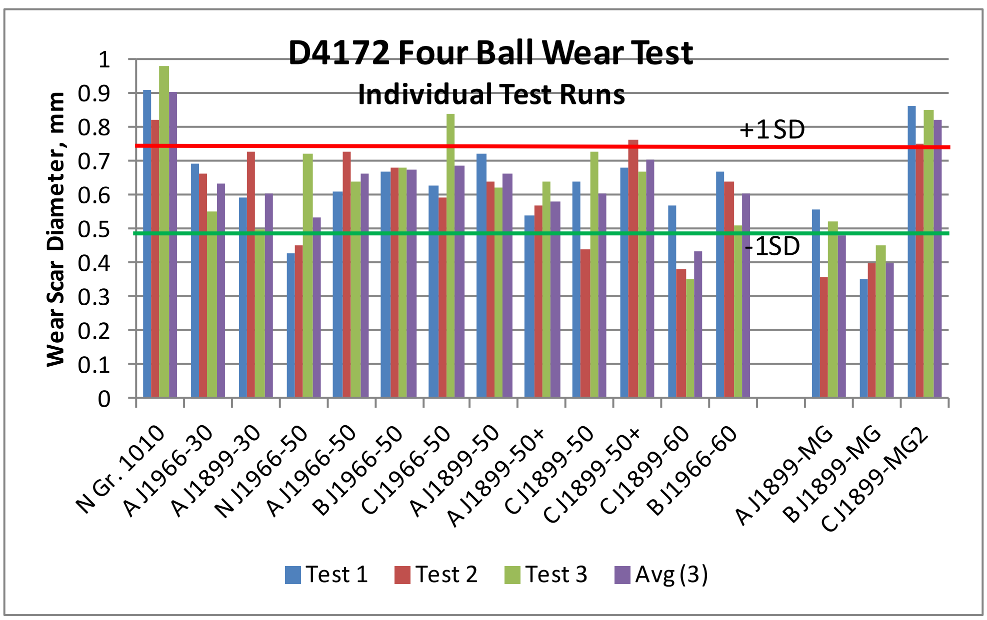

Figure 5. ASTM D4172 Four Ball Wear Test Results

The data show that all of the aviation J1966 and J1899 single grade products, regardless of viscosity grade, perform at relatively the same level. The one exception is the C J1899-60 sample which produced a slightly lower average wear scar result than the other single grade products. This sample provided results that were just within the repeatability limits of the method

consisting of the average of one high value and two low values. The low viscosity reference fluid, sample N Gr.1010, provided higher wear scar diameters than the SAE aviation products. The results obtained on this oil were as expected since it a low viscosity product and contains no anti-wear additives. The sample was evaluated to provide a reference value for comparison to the higher viscosity aviation products know to be used in catapult systems. The two PAO based multigrade SAE J1899 oils provided lower wear scar diameters than the either the mineral-based multigrade oil or the single grade products. The lower performance of the mineral-based multigrade oil was also not unexpected in that this product represents an older technology formulation which, aside from not benefiting from the PAO component, does not contain the anti-wear additives used in the other two multigrade samples.

Included in the test matrix were two SAE J1899 Grade 50 products containing an additional anti-wear additive (products marked as Grade 50+) along with samples of those same formulations without the additive. The results obtained indicate a slight decrease in the wear-scar diameter obtained with one manufacturer's products and a slight increase in diameter with the other. In both cases the differences measured were within the repeatability of the test method. The data is interesting because the specific additive used is mandated by the FAA to assist in the prevention of excessive valve train wear (due to high loads and high sliding contact conditions) in certain models of aircraft engines. The use of oils containing the required additive has proven to be very successful in actual engine use. Variables such as contacting part metallurgy specifics, contact temperatures and loads will of course be different and will greatly affect wear performance in actual systems versus test rigs. In this instance it appears that the D4172 test is not able to determine the effectiveness of the particular anti-wear additive under the conditions run.

4.3.2 ASTM D2783 Standard Method for Measurement of Extreme-Pressure Properties of Lubricating Fluids (Four Ball Method).

This test operates at the standard conditions of 1750 rpm at a starting temperature of 18- 35ºC and is run for 10 second durations at increasing loads until welding occurs. The resulting velocity is 13.2 inches per second at the three points of contact. At the end of the test two values are reported; the weld point and the load-wear index. The weld point is the lowest applied load at which the rotating ball welds to the stationary balls (in Kg). The load-wear index result is obtained following a process wherein the balls are loaded in ten progressive, specified increments prior to welding. The load-wear index value is the average of the sum of these corrected loads as defined by the test method. High weld point values and high load-wear index values suggest better extreme pressure performance. The same sixteen oils examined in the D4172 Four-Ball Wear Test were also evaluated using this method. The test data is provided in the D2783 Table of Appendix B along with supplemental graphs.
The results obtained on the Weld Point assessment show all sixteen products being equal within the repeatability of the test which is plus or minus one load stage. In this case all the products failed at either 250 Kg or the next higher stage of 315 Kg. The only observable difference is that some products provided consistent results in all three runs on that product (three products at 315 Kg and eight at 250 Kg) while the remaining five oils had either one higher or one lower result within their series of three runs. The Weld Point test results did not show much difference in product performance except perhaps suggesting that the three products with the consistent 315 Kg Weld Point are slightly better than those consistently measured at 250 Kg (Figure 6).

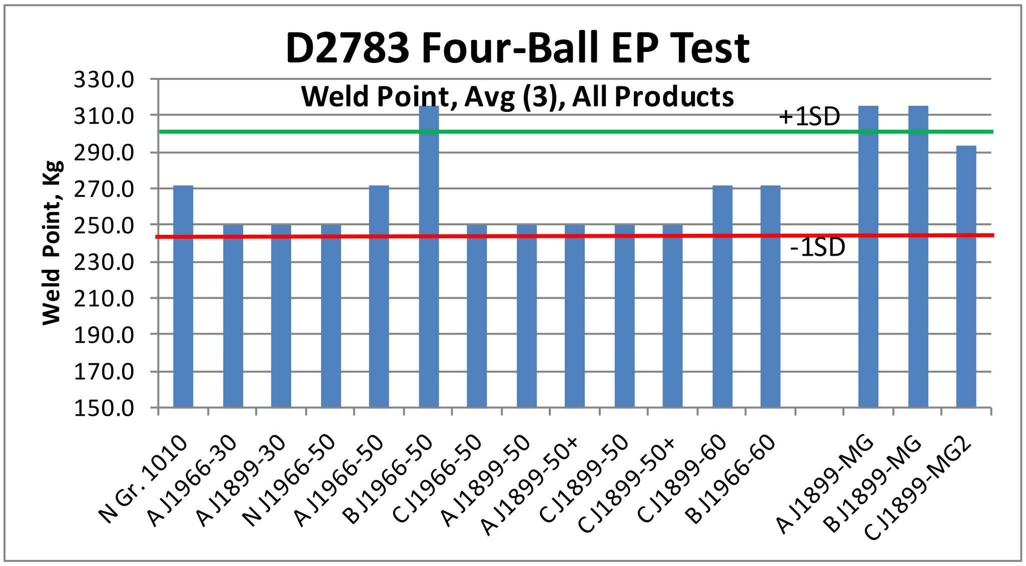

Figure 6. ASTM D2783 Four-Ball Extreme Pressure Test Results

The second reported item in the D2783 Test is the Load-Wear Index value. The data obtained is summarized in the graph below (Figure 7). As with the D4272 Four-Ball Wear Test there were five data points that appeared to be outliers when compared to the other results obtained on the same oil and the test method's precision statement. These suspect data were identified to the contractor during the previously noted discussion of the unusual data, Appendix A; however, no repeat testing was conducted. The suspect data is highlighted in red on the D2783 tab. In four of the five suspect runs the tests were run on different days than the other two runs on that same oil, sometimes the difference was several months apart. Similar to the Four-Ball Wear Test results these results are more representative of reproducibility than of repeatability and do not quite fit into the reported average of three runs on each oil. If these apparent outliers are left out of the average the low-viscosity reference oil drops in value while the single grade aviation oils become more similar to each other as do the two PAO based multigrade products. The dates of each test run, the highlighted suspect data and the average of just two runs is also provided in the D2783 tab for information. The below graph is the complete data reported and does not contain any adjustments (Figure 7). While the SAE Grade 30 products are at the lower end of the range overall, the Load-Wear Index values for the single grade aviation oils are essentially the same within the repeatability of the test method.

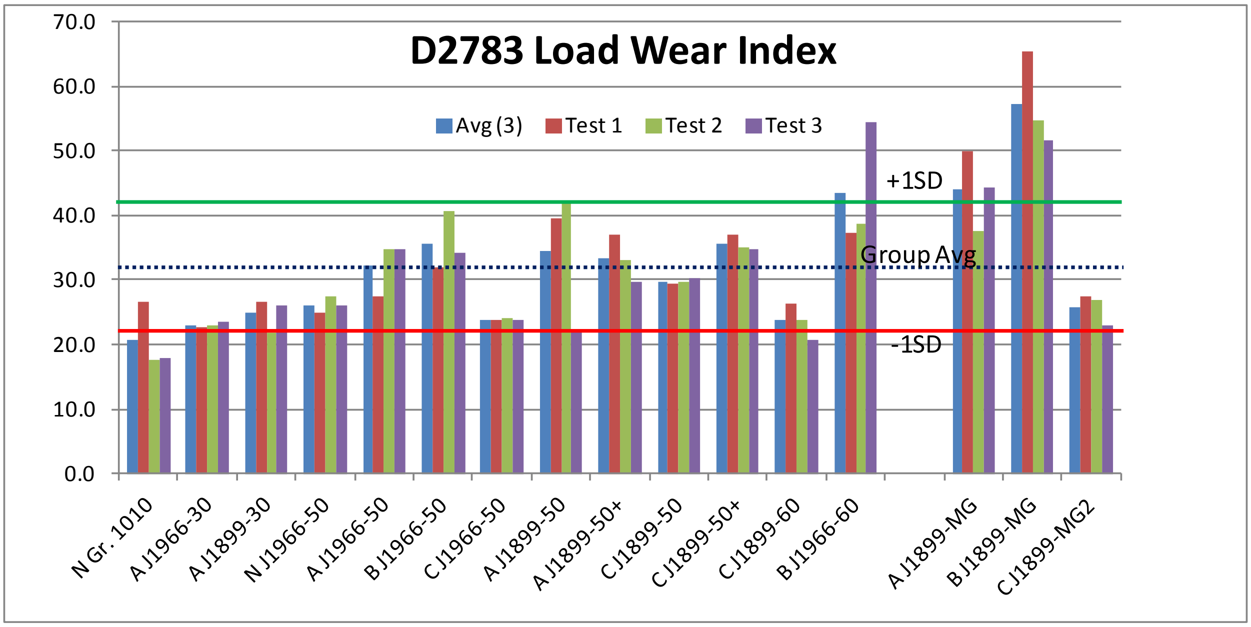

Figure 7. ASTM D2783 Load Wear Index Results

4.3.3 ASTM D5182 Standard Test Method for Evaluating the Scuffing Load Capacity of Oils (FZG Visual Method).

The FZG machine uses a pair of spur gears to evaluate the scuffing resistance of lubricants. The machine operates at 1450 rpm for 15 minutes at successively increasing loads until the failure point is reached. Starting at the fourth load stage the oil temperature begins the run at 90ºC and is uncontrolled thereafter. The pitch line velocity of the gear pair is 328 inches/second. The sliding velocity at the contact will vary from zero at the pitch line to a maximum at the tip and root of each gear tooth as the gear progresses through its normal engagement cycle. After each load stage the gears are visually examined for the presence of scuffing. The test is terminated when the summed total of scuffing on all 16 teeth of the pinion gear is estimated to equal or exceed 20 mm (the width of one gear tooth) and that load is reported as the failure load stage. As with both Four-Ball test methods, higher load stage values in the FZG test indicate better anti-scuff performance of the test lubricant. Additional measurements are also made at the end of the test: the individual weight of the pinion and gear, the pinion gear scuff, and the pinion gear scoring. Calculations are performed and the results are reported for the combined weight loss of the gear pair, the drive gear scuffing, the drive gear scoring, the total pinion gear wear rating and the total drive gear wear rating. (The gear wear rating is the sum of the amount of scuffing and scoring measured. It is measured on the pinion gear and then calculated for the drive gear.) The temperature of the oil at the failure load stage and the previous pass load stage are also reported. The summarized test data is provided in the D5182 Table of Appendix B along with supplemental graphs.

The most relevant data generated in the D5182 gear test appears to be the reported "failure load stage" value as shown in the following graph (Figure 8). The results are well within the two load stage repeatability limit specified in the test method. The other parameters reported generated widely variable results for products that had relatively repeatable failure load stage values and

appear to have no correlation with the failure load stage measured as illustrated in the supplemental graphs associated with the D5182 data in Appendix B.

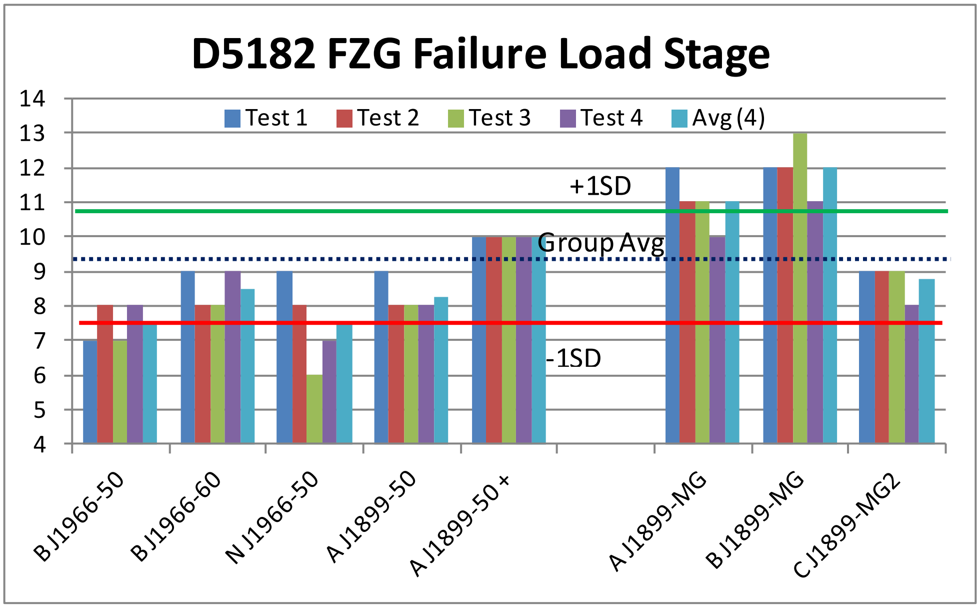

Figure 8. ASTM D5182 FZG Failure Load Stage Results

The PAO based multigrade products provided the highest failure load stage results. One product, sample B J1899-MG, completed one of its three test run without reaching the tooth scuffing/scoring failure criteria. That data was reported as “exceeds load stage 12” but for calculation and illustration purposes it is shown with a failure load stage of 13. The mineral based multigrade oil provided the lowest total gear weight loss and lowest pinion gear wear rating within that test group. That oil also produced a very consistent failure load stage value which was similar to that measured for the single grade product group. The oil containing the FAA specified anti-wear additive, sample A J1899-50+, produced the most consistent failure load stage results. The values obtained were almost two load stages greater than that same formulation not containing the anti-wear additive (sample A J1899-50). Excluding the multigrade products, the remaining single viscosity grade lubricants provided very comparable results with the 50+ sample giving measurably better than average performance in the single grade test group (Figure 9).

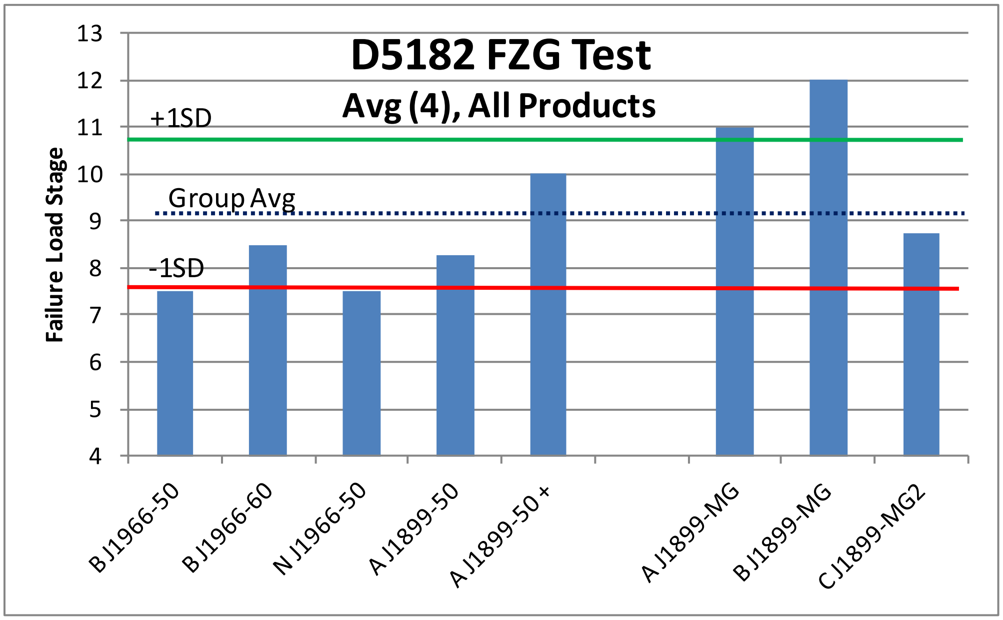

Figure 9. ASTM D5182 FZG Test Results Averaged

4.4. Correlation of Sulfur Content on Test Results.

4.4.1. The sulfur content of a lubricant can have an effect on the oxidative and / or anti-wear or load carrying capacity of the product. The sulfur content of the SAE J1966 and J1899 products is measured on the qualification sample and it must be maintained within a range of 0.30% by specification requirement. This is one parameter used to define the base oil's origin and to insure consistent processing quality. The value measured is the total sulfur content of the oil. However, there are several different sulfur compounds that may be present in mineral based oil, some are good and may enhance performance while others may detract from it. There is no requirement to define and control the various types of sulfur compounds in the lubricant, only that the product must perform to the specification requirements with the amount of sulfur with which it was originally qualified.

4.4.2. The test results obtained in this program were compared against the sulfur content of the various products. There appears to be no correlation between the sulfur content and the oxidative performance of the oils in the D943 and D2272 oxidation tests. There also does not appear to be any correlation to the anti-wear performance in the D5182 FZG Gear Test, the D4172 Four-Ball Wear Test or the Weld point measurement of the D2783 Four-Ball EP test. There did appear to be a modest correlation of the sulfur content with the Load Wear Index measurement of the D2783 Test. While there appears to be an improvement in the load wear index with increasing sulfur content the large increase in the sulfur values of the last two samples did not proportionally increase the load wear index of the test products. The correlation is better if the results of the two PAO based multigrade samples are not considered in the analysis. The correlation using all the data is show in the below graph (Figure 10) and all the comparisons are provided in the Test vs %Sulfur in Appendix C. For better visualization some of the graphs show the sulfur content times 100.

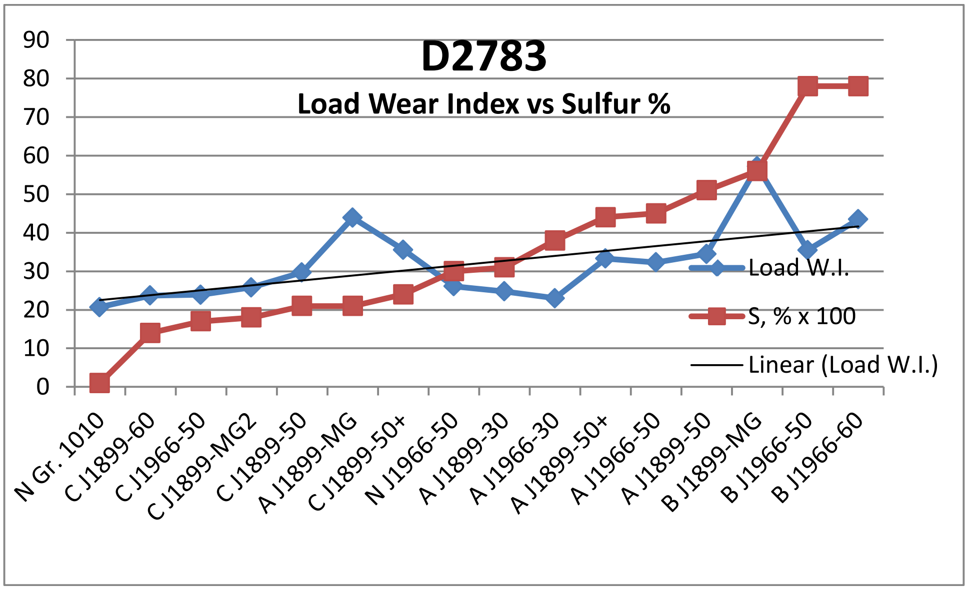

Figure 10. ASTM D2783 Load Wear Index Versus Sulfur %

5.0 CONCLUSIONS

5.1. The goal of this program was to develop a replacement specification or Commercial Item Description (CID) for the LA7 aircraft catapult launch system lubricant that will provide adequate performance and be readily obtainable in bulk quantities by the procurement community. A CID can be developed using selected requirements from the existing SAE J1899 Grade 50 Standard in combination with the data generated in this project.

5.2. The results from the long-term D943 test and the related D2272 short-term tests showed all the mineral oil based aviation oils to be comparable in performance to each other regardless of viscosity grade or SAE Standard (dispersant or non-dispersant). The two PAO based multigrade oils performed much better in the D2272 test than the single grade oils. The results obtained were very low compared to those obtained with steam turbine oils but demonstrated that the current aviation products perform at a relatively consistent level. Since oil oxidation does not appear to be a problem in the current catapult systems the levels displayed in these tests should be considered adequate. Of the two, the D2272 method provided the most consistent results in the shortest time. A minimum oxidation time of 95 minutes over four test runs would appear to be adequate for these oils.

5.3. The results obtained in the D4636 oxidation test are unusable as the data are completely unrecognizable from the earlier investigative test runs by the Navy. The D4636 test is the main oxidation test used for MIL-PRF-23699 gas turbine engine lubricants and better results were expected from this contracted effort. The complete failure of the D4636 oxidation test series prevented measuring the oxidation performance profile of the commonly used SAE J1966 and J1899 oils. However, all of the oils examined in this test have been providing acceptable field service in aviation piston engines for several years and their oxidative performance is without question. While valid D4636 test data would have been more desirable for the development of

the CID requirements the lack of having that data was not fatal to the program's goal. As noted in the preceding paragraph, the oxidative assessment of these field-tested oils using the D2272 method showed the test products to have comparable performance.

5.4. The D4172 Four-Ball wear data indicates that all the mineral oil based aviation piston engine oils provide essentially the same level of anti-wear protection while the PAO based multigrade oils performed slightly better. In this test the two SAE J1899-50+ products (containing a specific anti-wear additive) provided results that were not statistically different than those same products without the additive.

5.5. Two items for each of oils examined in the D2783 Four-Ball Extreme Pressure test; Weld Point and Load Wear Index. The Weld Point values of all the products were essentially the same, varying by only one load step between them over the entire range of products. The Load Wear Index values permitted more of a ranking ability. In general the products can be ranked by viscosity with the lower viscosity products performing worse than the higher viscosity oils. Again, the two PAO based multigrade oils were at the top of the rating. One unusual item was that manufacturer C's products consistently provided lower Load Wear Index results than the other manufacturers products of the same type and grade.

5.6. The Failure Load Stage values reported for the D5182 FZG gear test provided the most consistent means of evaluating the products tested. Of the eight oils tested the two PAO based multigrade oils again provided the best results. Five of the remaining six oils produced results that were comparable to each other. The sixth oil in that group, sample A J1899-50+ (containing the specified anti-wear additive) performed slightly better than the others, but not as well as the PAO based products.

5.7. An unexpected discovery in this evaluation was the superior performance of the two PAO based multigrade products in all categories examined. The oxidative stability performance requirements of the catapult launch system apparently does not exceed the capabilities of the conventional mineral oil based aviation products used today, so the improved oxidative stability available with the PAO based oils may not be necessary. However, the anti-wear performance of the currently used mineral based oils in the catapults is reported to be somewhat marginal and better performance is desirable. It is unclear if the multigrade PAO base products would provide better anti-wear preformance in catapult applications than the conventional mineral oil based products.

5.8. There appears to be a modest correlation between the sulfur content of the test oils and the Load Wear Index value measured in the D2783 Four-Ball EP Test. None of the other tests performed correlated the sulfur content with the oxidative performance or the anti-wear or load carrying capacity of the test products.

6.0 RECOMMENDATIONS

6.1. A CID should be developed using the basic property requirements of the current SAE J1899, Grade 50 Ashless Dispersant Aircraft Piston Engine Lubricating Oil in conjunction with

the test results from this program. Not all of the J1899 property tests would be required for the catapult application since it is not a combustion engine with a circulating oil system.

6.2 The recommended CID requirements are shown below in Table 1. The CID should be proposed to the NAVAIR Lakehurst catapult team before being utilized for procurement.

6.3 The improved anti-wear and anti-scuffing performance of the PAO based multigrade aviation oils should be further investigated in larger, more complex test devices.

6.4. It is not recommended that any full scale catapult testing be performed using the PAO based aviation oils tested in this evaluation.

6.5. If funding is available, the D4636 oxidation test series should be repeated at a different contract laboratory in order to define the oxidative performance characteristics of currently used catapult oils.

7.0 REFERENCES

a. SAE J1966, Lubricating Oils, Aircraft Piston Engine (Non-Dispersant Mineral Oil)
b. SAE J1899, Lubricating Oil, Aircraft Piston Engine (Ashless Dispersant)
c. ASTM D-6709, Standard Test Method for Evaluation of Automotive Engine Oils in the Sequence VIII Spark-Ignition Engine (CLR Oil Test Engine)
d. FED-STD-791, Method 5308, Corrosiveness and Oxidation Stability of Light Oils (Metal Squares)
e. ASTM D4636, Standard Test Method for Corrosiveness and Oxidation Stability of Hydraulic Oils, Aircraft Turbine Engine Lubricants, and Other Highly Refined Oils
f. ASTM D943, Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils
g. ASTM D2272, Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel
h. ASTM D5182 Standard Test Method for Evaluating the Scuffing Load Capacity of Oils (FZG Visual Method)
i. ASTM D4172 Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method)
j. ASTM D2783 Standard Test Method for Measurement of Extreme-Pressure Properties of Lubricating Fluids (Four-Ball Method)

Table 1. Proposed Requirements For A Dedicated Mineral Oil Based Catapult Lubricant

Characteristic (Limits) SAE GRADE	50	Test Method
Viscosity, mm^2/s (cSt), @ 100 °C, Min @ 100 °C, Less than	 16.3 21.9	ASTM D 445
Viscosity, mm^2/s (cSt), @ 40 °C	 report	ASTM D 445
Viscosity Index, Min	95	ASTM D 2270
Flash Point, °C, Min	243	ASTM D 92
Pour Point, °C, Max	-18	ASTM D 97, ASTM D 5949, ASTM D 5950, ASTM D 5985
Sulfur, Mass %, Max	1.0	ASTM D 129, ASTM D 1552, ASTM D 2622, ASTM D 4951, ASTM D 5185
Viscosity, High Temp., High Shear, at 150 °C, cP, Min	3.7	ASTM D 4683, ASTM D 4741, ASTM D 5481
Acid Number, mg KOH/g, Max(1)	 1.0	ASTM D 664
Density, @ 15 °C, g/mL	report	ASTM D 4052
Gravity, @ 60 °F, °API(2)	report	ASTM D 1298, ASTM D 4052
Trace Sediment, mL/100 mL Oil, Max	 0.005	ASTM D 2273
Copper Strip Corrosion,(3) Max Rating 3 h @ 100 °C 3 h @ 204 °C	 1 3	ASTM D 130
Foaming Tendency/Stability Seq. 1 Aerated Vol., mL, Max Vol. after 10 min, mL, Max Seq. II Aerated Vol., mL, Max Vol. after 10 min, mL, Max Seq. III Aerated Vol., mL, Max Vol. after 10 min, mL, Max	 50 0 50 0 50 0	ASTM D 892
Oxidation Stability Minutes, Min	 95	ASTM D 2272
Four-Ball Wear Test (Avg of 3), 40 kg load Wear Scar Diameter, mm, Max	 0.75	ASTM D 4172
Four-Ball EP Test (Avg of 3) Weld Point, Kg, Min Load Wear Index, Min	 250 30.0	ASTM D 2783
FZG Gear Test (Avg of 2) Failure Load Stage, Min	 7.0	ASTM D 5182
Workmanship,(4)	(4)	(4)

.

1. Titrate to a pH 11 end point.
2. API gravity may be computed from the relative density measured by ASTM D 4052
3. Conduct the test in accordance with ASTM D 130 but at the temperature specified
4. The lubricaing oil shall be homogeneous blend when examined visually at room temperature (25 °C +/- 3 °C) in a well-lighted room or in daylight. It shall exhibit no separation or fallout of the additive package. A jelly-like substance or very viscious material observed in the bottom of the container will be evidence of additive fallout.

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Appendix A

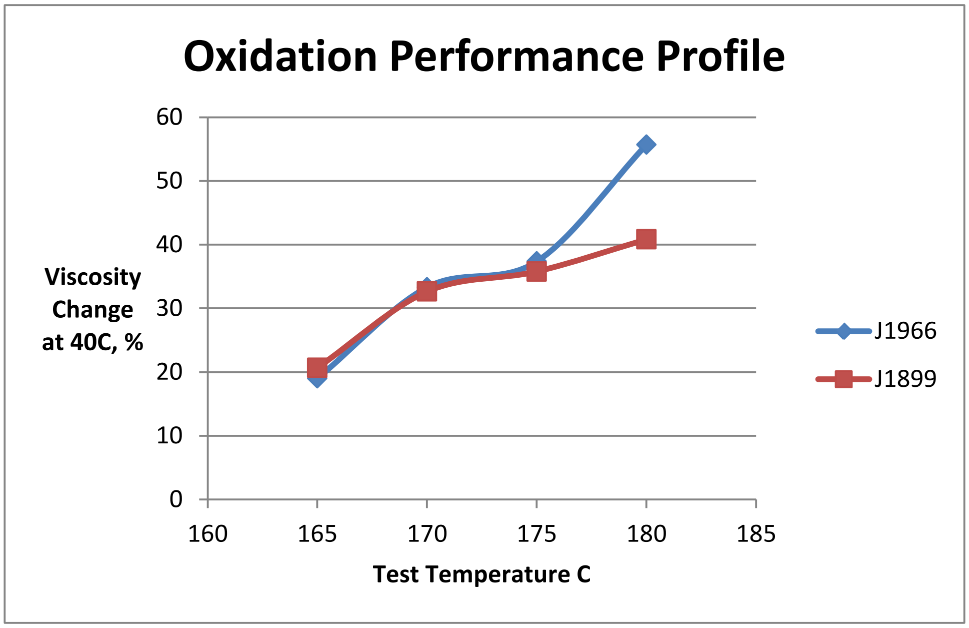
****NOTE- This version has been edited to remove company name identifications ****
MEMORANDUM
To: Jim McDonnell **27 March 2013**
From: John Shimski
Subject: Test Data from Intertek

A. Background.

1. This is submitted as a follow-up to our discussion of the Intertek test data last week. Perhaps you could pass them along to the folks at Intertek to let them know what seems amiss and ask for their comments. The test data from the tests in question are included in the reference Excel file along with our baseline D4636 data. The file has four tabs each of which are discussed individually below. The irregular performance of the products in the D4636 tests is the most serious concern. There also appears to be a few abnormalities in the D4172 Four-Ball Wear test and to a lesser degree in the D2783 Four-Ball EP test.

B. Discussion.

1. Tab 4636dev. As you know these data are from the development tests we ran to define the temperature ranges to use in the D4636 contract oxidation tests. We picked this test because we have been using it for the MIL-PRF-23699 turbine engine oils since the 1960's and believe it provides a good picture of oxidation performance over a reasonable range of temperatures, we just needed to lower them for the piston engine oils. In the development effort we used two single grade oils, one a J1966 non-dispersant oil and the other a J1899 dispersant grade, both SAE 50's. The J1966 product was not re-run at Intertek but the J1899 was (A J1899-50+ – but it was a different batch than what Intertek ran.) With the exception of the two tests at 180ºC all the tests were run in duplicate. The data on this tab shows the expected performance of these single grade oils both in tabular and graphic form. The main properties we are looking at are really the viscosity and TAN changes while the metal weight changes and sediments are really secondary. This single viscosity graph below sums it up fairly well.



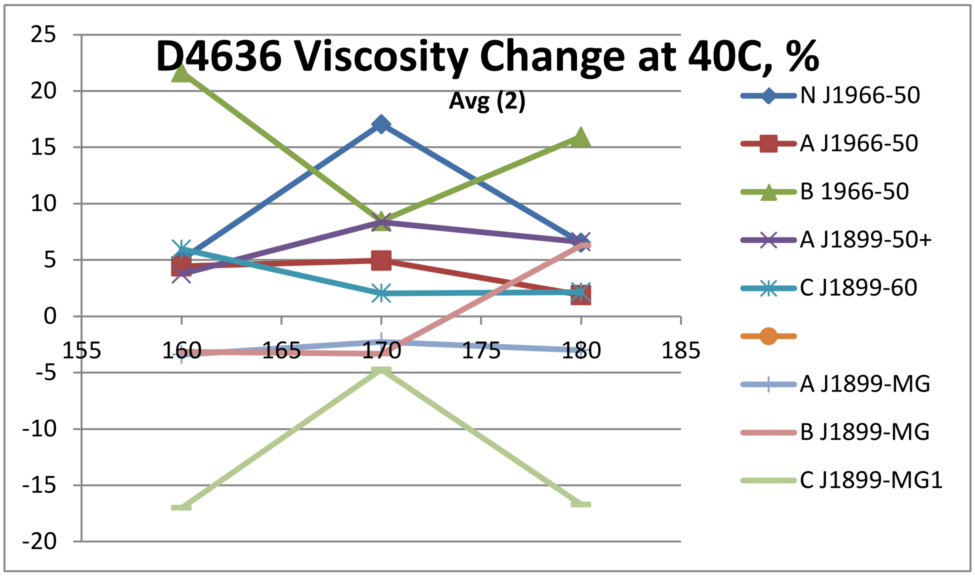
The test development data shows:

a. There is the step-like progressive increase in the post-test oil property changes for both viscosity at 40ºC and Total Acid Number (TAN) as the test temperatures increased.
b. There is the typical relationship between the viscosity change and TAN change for each test (small change in viscosity = small change in TAN, or big viscosity change = big TAN change).
c. The magnitude of the viscosity and TAN changes across the range of test temperatures reflects the desired level of moderate to heavy degradation targeted for this evaluation.
d. The tests show good repeatability.

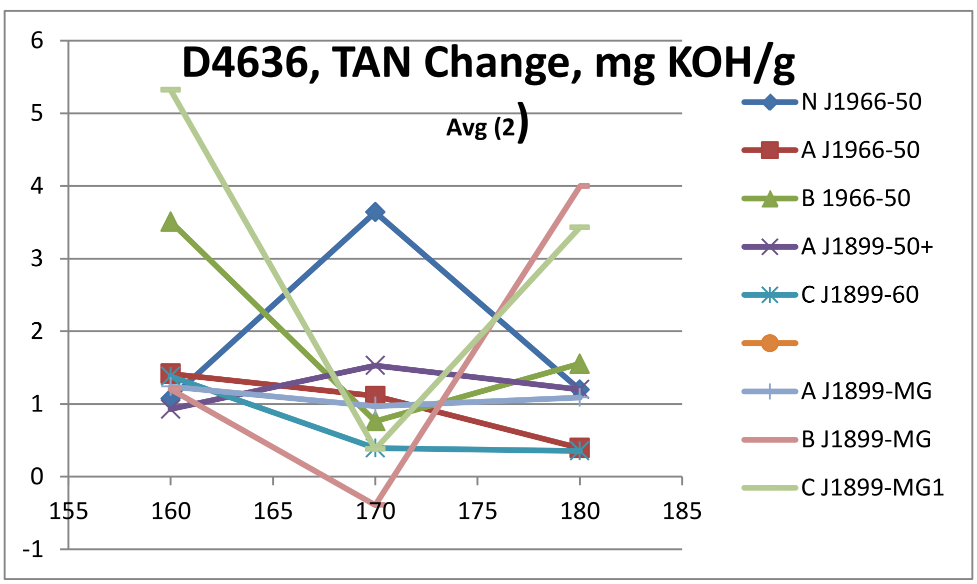
NOTE: In our development tests we used the normal five metal coupon suite used for the 23699 oils: Iron, Aluminum, Copper, Magnesium and Silver. I see that in the Intertek tests they used Cadmium in place of the Silver coupon. I do not think this alone can explain the vast differences we see in the test results. As far as I know Cadmium is not an oxidation inhibitor nor is it a catalyst.

Development Conclusion: This development phase provided a reasonable set of conditions to evaluate the test oils. By using the general rule that oxidation doubles with each ten degree Centigrade increase in temperature, oxidation performance profiles were produced for two representative aviation piston engine oil products.

2. Tab D4636sum. I originally designed the spreadsheet before any data was received. I formatted it into three basic test temperature tables with identical product listing and performance measurements for each individual test (1 and 2) and the average of the two. Data from these tables would then be rearranged to develop the graphs shown. When received, the data was then entered into the template and the results emerged. A quick look at the graphs shows that the tests, particularly on the single grade oils, did not turn out anything like our development tests suggested. (Note: we did expect to see a serious drop in viscosity for the multi-grade (MG) oils due to degradation of the dispersant/VI additive. However, the overall data for the MG oils still shows problems as will be discussed further).



a. This viscosity change graph presents the average value obtained on each test and dampens the wide range experienced between the two test runs at each temperature.
b. As noted for the development testing, the focus on these contract tests was on post-test viscosity change at 40ºC and TAN change. From the tables several discrepancies were apparent.
c. The repeatability between test 1 and 2 was generally not good. For reference, only the viscosity change is highlighted in the tables in the D4636sum tab, but the observation is also true for the TAN change.



d. The typical relationship between the viscosity and TAN changes (small = small and big = big) are present in most tests (except B J1899-MG test 2), however, the results vary widely. This suggests that each of the test pairs experienced a different level of stress (time, temperature, airflow, condenser temperature, etc.). I originally thought that the test samples may have been

switched, but the end-of-test dates for all but one sample show that the products were run in pairs at the same time.

e. The magnitude of the viscosity changes for the 170ºC and 180ºC test temperatures were nowhere near those measured during the development testing. Data for the 160ºC test temperature may be in the right ballpark but the repeatability of the group is so poor you cannot identify the proper value. Only one product in the 160ºC test group was consistent, B J1966-50, but its' property changes were higher at 160ºC than they were for either the 170ºC or 180ºC test temperature. In addition, the performance of the sample C J1899-60 was consistently low and was essentially unchanged over the entire three-temperature test range.

f. From the graphs, the individual performance trend-line for any given oil product does not follow the normal increase in viscosity/TAN change expected to occur with increasing test temperature (as predicted in the development tests). In fact, the test data for the 170ºC test temperature shows a significant drop in the TAN change compared to those measured at the 160ºCand 180ºC condition.

g. The major concern is with the unexpected performance of the single grade products. Different batches of the same product, A J1899-50+, were run in both the development program (marked as J1899 on that graph) and as A J1899-50+ in the graphs for the Intertek data. The data are in no way comparable.

h. In general, the data for the multi-grade oils was not unexpected (except in two instances.) Thermal degradation of the dispersant / VI additive was expected resulting in a sharp drop in viscosity and increase in TAN values. However, previous test experience has shown that this is usually just true for tests run at the lower temperatures. At the higher test temperatures the viscosity loss occurs early in the test duration and then is overcome by the oxidation of the oil component, resulting in a higher post-test viscosity measurement than obtained in test run at the lower values (although it can still be lower than the new oil viscosity.) In this regard, the performance profile of sample C J1899-MG1 does not fit the norm in that it displays a high loss at 160ºC and 180ºC, but not at 170ºC.

i. The multi-grade sample B-J1899-MG viscosity and TAN changes at the 180ºC condition are unusual in that while the TAN changes are repeatable, and in the expected range, the viscosity values differ by a factor of more than ten between test 1 and 2 (test numbers 201167oce and 201167ocd).

k. With few exceptions the metal weight change data for all the tests performed were uneventful. The Copper attack for one product (A J1899-MG) was higher than any other product, but all products showed some change. The Cadmium weight change values were comparable for all products except one (C J1899-MG1) which displayed sever attack at 160ºC and 180ºC, but not at 170ºC (the 170ºC test on that oil also had lower viscosity and TAN changes than either the 160ºC or 180ºC tests).

D 4636 Conclusions: The D4636 data delivered is so inconsistent that it will be of little use for the evaluation program. It is almost as if the data were from a different test than the one used during the Navy's temperature development phase. As aforementioned, these tests used a Cadmium metal coupon instead of the Silver coupon used in the development testing. I do not believe that the use of the Cadmium alone can explain the poor test repeatability and the unusual performance trending profiles displayed in the attached graphs.

3. Tab D4172sum. From in-house test experience Four-Ball Wear test data can typically be difficult to analyze. Data point outliers can periodically and inexplicably show-up. In the testing at Intertek three tests were run on each product and each test consisted of two runs, thus resulting in six reported data points for each product. The vast majority of products tested produced consistent results across all runs.

However, four products produced highly unusual results in one test (two runs) when compared against data from its' other two tests (four runs). Three other oils also produced similarly suspicious results but not to the magnitude of the first group. In sorting the data it appeared that three of the four major outlier points occurred on the same test day (11 January) while one major and one minor occurred on a second test day (7 February). The data is shown below with the dates color coded and the major outliers in bold print. Also shown is the standard deviation for data from each product with the four major problem items in red and the three minor in orange.

		ASTM D4172, Four-Ball Wear Test							repeat	0.12		
		40 Kg	1750 rpm	60 minutes					Repro	0.28		
		Wear Scar Diameter, mm										
Mfgr / Type	Avg (6)	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6		Std Dev	avg (4)	date run		
N Gr. 1010	0.90	0.91	0.91	0.82	0.82	0.98	0.98		0.07		10-Dec	15-Jan	15-Jan
A J1966-30	0.63	0.67	0.70	0.66	0.65	0.54	0.56		0.06		18-Jan	18-Jan	7-Feb
A J1899-30	0.60	0.59	0.58	0.72	0.73	0.49	0.51		0.10	???	18-Jan	25-Jan	7-Feb
N J1966-50	0.57	0.42	0.44	0.45	0.45	**0.84**	**0.81**		0.20	0.44	26-Nov	26-Nov	**7-Feb**
A J1966-50	0.66	0.60	0.61	0.72	0.74	0.64	0.64		0.06		10-Dec	15-Jan	7-Feb
B J1966-50	0.68	0.67	0.67	0.68	0.67	0.68	0.68		0.01		13-Nov	13-Nov	13-Nov
C J1966-50	0.73	0.63	0.63	0.58	0.59	**0.97**	**0.97**		0.19	0.6075	15-Jan	15-Jan	**11-Jan**
A J1899-50	0.66	0.71	0.73	0.66	0.62	0.61	0.63		0.05		25-Jan	25-Jan	25-Jan
A J1899-50+	0.58	0.54	0.54	0.58	0.56	0.64	0.63		0.04		15-Jan	15-Jan	15-Jan
C J1899-50	0.82	0.63	0.64	*0.44*	*0.43*	**1.40**	**1.35**		0.44	0.535	11-Jan	*11-Jan*	**11-Jan**
C J1899-50+	0.70	0.67	0.69	0.74	0.78	0.67	0.66		0.05		11-Jan	11-Jan	11-Jan
C J1899-60	0.43	0.57	0.57	0.38	0.38	0.35	0.34		0.11	0.3625	26-Nov	15-Jan	15-Jan
B J1966-60	0.60	0.66	0.67	0.64	0.64	0.50	0.51		0.08		13-Nov	13-Nov	15-Jan
A J1899-MG	0.48	0.56	0.55	*0.35*	*0.36*	0.52	0.51		0.09	0.535	18-Jan	*18-Jan*	18-Jan
B J1899-MG	0.40	0.35	0.35	0.39	0.40	0.44	0.45		0.04		13-Nov	16-Jan	16-Jan
C J1899-MG2	1.03	0.84	0.88	**1.34**	**1.39**	*0.86*	*0.84*		0.26	0.855	11-Jan	**11-Jan**	*11-Jan*

a. The major problem in handling the data analysis is that I am not sure if the bolded values are indeed outliers, or if they are actually from a different product than that indicated. The fact that three of the four apparent outliers were run on the same test day (11 January) and have the same general magnitude could indicate a product misidentification. The same concern holds true for the apparent outlier in the block of data from 7 February. I believe the only way to resolve the question will be run repeat tests on the suspect products.
b. However, and of a more serious concern is, if those three high values are all from the same product, which one is it?

D4172 Conclusions: There is some inconsistency in the data and at least four tests, and possibly seven, should be re-run.

4. Tab D2783. The data for the Four-Ball Extreme Pressure (EP) Test has some apparent Load Wear Index outliers similar to those experienced in the D4172 Four-Ball Wear Test, but to a lesser extent. The data table again uses colors for reference with red indicating possible outliers and the other colors to identify test run dates. The Load Wear Index values and dates for the suspect tests are also in bold print.

	ASTM D2783, Four-Ball Extreme Pressure Test					repeat	17% of mean		
	Load Wear Index					repro	44% of mean		
Mfgr / Type	Avg (3)	Test 1	Test 2	Test 3		Avg (2)	Test 1	Test 2	Test 3
N Gr. 1010	20.7	**26.5**	17.6	18.0		17.8	**16-Nov**	28-Feb	28-Feb
A J1966-30	23.0	22.6	22.9	23.4			18-Feb	18-Feb	18-Feb
A J1899-30	24.8	26.7	21.9	25.9			28-Feb	28-Feb	28-Feb
N J1966-50	26.1	24.8	27.5	26.1			28-Feb	28-Feb	28-Feb
A J1966-50	32.3	27.3	34.8	34.7			13-Feb	13-Feb	28-Feb
B J1966-50	35.5	31.8	40.5	34.1			13-Nov	13-Nov	13-Nov
C J1966-50	23.9	23.9	24.1	23.7			18-Feb	18-Feb	28-Feb
A J1899-50	34.5	39.4	42.1	**22.1**		40.8	28-Feb	28-Feb	**28-Feb**
A J1899-50+	33.3	37.1	33.0	29.7			28-Feb	28-Feb	28-Feb
C J1899-50	29.7	29.5	29.6	30.1			28-Feb	28-Feb	28-Feb
C J1899-50+	35.6	37.1	35.0	34.7			28-Feb	28-Feb	28-Feb
C J1899-60	23.7	26.4	23.8	20.8			13-Feb	13-Feb	13-Feb
B J1966-60	43.5	37.2	38.7	**54.5**		38.0	7-Feb	7-Feb	**13-Feb**
A J1899-MG	43.9	**50.0**	37.5	44.2		40.9	**20-Feb**	18-Feb	28-Feb
B J1899-MG	57.2	**65.4**	54.6	51.6		53.1	**15-Nov**	13-Feb	13-Feb
C J1899-MG2	25.8	27.5	27.0	23.0			28-Feb	28-Feb	28-Feb

a. The first observation is that the data is fairly consistent for tests performed on a single product wherein all the tests were completed on the same day, with a few exceptions. Most of the conflicting data occurs where the test series for a particular product was performed over two or more days.

b. On two test dates in particular, 13 and 28 February, multiple products were tested. Three, two or in some cases only one test was performed on each product. In looking at the bolded data for these days, it appears that some sample results, or the test products, may have been mixed. For instance, the single run on sample B J1966-60 on 13 February produced results that more closely match the two values obtained on the B J1899-MG product tested on the same day. Also, data for the A J1966-50 of 28 February is out of place with the results from its' other two tests (run on 28 February), and more closely match the values of the MIL-PRF-6081 oil (sample N Gr. 1010), which coincidently, was also run twice on 28 February.

c. The single test data points for the individual products run on 15 and 16 November are different than the values obtained on the same oils when they were each run in duplicate (on either 13 or 28 February respectively). Due to the time span between the testing those early results may more reflect the tests' reproducibility than its repeatability.

D2783 Conclusions: The suspect tests should be re-run to confirm their values.

C. General Conclusions:

1. With the exception of the D4636 results the Intertek data is useful. Confirmation tests should be run on a number of oil samples in the D4172 and D2783 tests to address repeatability observations.

2. It is doubtful if the data from the D4636 tests can be salvaged.

4/11/2012 **ASTM D4636, Procedure 2, Development Tests**

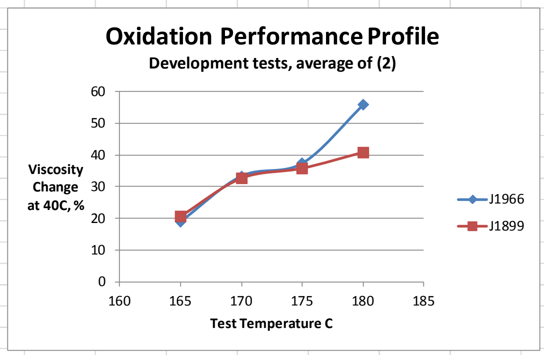
Tab 4636dev

	J1966, SAE 50			J1966, SAE 50			J1966, SAE 50			J1966, SAE 50		
	165 C	165 C	Avg (1)	170 C	170 C	Avg (2)	175 C	175 C	Avg (2)	180 C	180 C	Avg (1)
40 C Viscosity Change, %		18.99	18.99	34.35	32.26	33.31	37.84	36.88	37.36		55.7	55.7
TAN Change, mgKOH/g		2.08	2.08	2.56	2.47	2.52	2.48	2.57	2.53		4.16	4.16
Metal Weight Change, mg												
Fe		0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01		0.01	0.01
Ag		-0.05	-0.05	-0.05	-0.06	-0.06	-0.06	-0.05	-0.06		-0.05	-0.05
Al		0.00	0.00	-0.01	0.00	-0.01	-0.01	0.00	-0.01		0	0
Mg		0.01	0.01	0.00	0.03	0.02	0.02	-0.01	0.01		0.01	0.01
Cu		-0.26	-0.26	-0.33	-0.30	-0.32	-0.25	-0.29	-0.27		-0.27	-0.27

	J1899, SAE 50			J1899, SAE 50			J1899, SAE 50			J1899, SAE 50		
	165 C	165 C	Avg (2)	170 C	170 C	Avg (2)	175 C	175 C	Avg (2)	180 C	180 C	Avg (1)
40 C Viscosity Change, %	22.85	18.49	20.67	33.35	31.92	32.64	35.76	35.81	35.79		40.83	40.83
TAN Change, mgKOH/g	2.59	2.25	2.42	2.64	2.61	2.63	2.77	3.02	2.90		3.65	3.65
Metal Weight Change, mg												
Fe	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01		0	0
Ag	-0.04	-0.03	-0.04	-0.02	-0.02	-0.02	-0.02	-0.03	-0.03		-0.02	-0.02
Al	-0.01	0.00	-0.01	0.01	-0.01	0.00	0.00	-0.01	-0.01		-0.01	-0.01
Mg	0.00	0.02	0.01	0.02	0.01	0.02	0.00	0.00	0.00		0.02	0.02
Cu	-0.12	-0.10	-0.11	-0.14	-0.15	-0.15	-0.24	-0.17	-0.21		-0.2	-0.2

Test Temp	J1966	J1899
165	18.99	20.67
170	33.31	32.64
175	37.36	35.79
180	55.7	40.83

	J1966, SAE 50	
	165 C	
40 C Viscosity Change, %	31.85	
TAN Change, mgKOH/g	3.14	
Metal Weight Change, mg		
Fe	0.02	
Ag	-0.06	
Al	0.02	
Mg	1.84	
Cu	-1.89	
	VOID	Isuspect two coupons were mixed pre and post test



Tab D4636

D4636 @ 160C	40 C Viscosity Change, %			TAN Change, mg KOH/g			Al weigh change, mg			Cu weight change, mg			Cd weight change, mg			Fe weight change, mg			Mg weight change, mg		
	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)
N J1966-50	2.13	7.96	5.045	0.32	1.83	1.075	0	0	0	0.4	0.4	0.4	0.1	0	0.05	0	0	0	0	0	0
A J1966-50	1.08	7.78	4.43	0.35	2.48	1.415	0	0	0	0.4	0.2	0.3	0.2	0.3	0.25	0.1	0.2	0.15	0	0	0
B 1966-50	20.5	22.79	21.645	3.08	3.94	3.51	0	0	0	0.4	0.3	0.35	0.3	0.2	0.25	0.1	0.1	0.1	0	0.2	0.1
A J1899-50+	5.65	1.85	3.75	1.48	0.38	0.93	0	0	0	0.6	0.3	0.45	0.2	0.2	0.2	0	0	0	0.1	0.2	0.15
C J1899-60	10.12	1.82	5.97	2.42	0.34	1.38	0	0	0	0.4	0.2	0.3	0.1	0.1	0.1	0	0	0	0	0	0
A J1899-MG	-4.38	-2.41	-3.395	1.21	1.27	1.24	0	0.1	0.05	3.1	1	2.05	1.2	1.4	1.3	0.1	0	0.05	0	0	0
B J1899-MG	-3.16	-3.16	-3.16	1.27	1.14	1.205	0	0.1	0.05	0.7	0.1	0.4	0.9	0.2	0.55	0	0	0	0	0	0
C J1899-MG1	-19.96	-14.06	-17.01	3.71	6.93	5.32	0	0	0	0.1	0.9	0.5	21.6	25.5	23.55	0.7	0.1	0.4	0	0	0

D4636 @ 170C	40 C Viscosity Change, %			TAN Change, mg KOH/g			Al weigh change, mg			Cu weight change, mg			Cd weight change, mg			Fe weight change, mg			Mg weight change, mg		
	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)
N J1966-50	15.09	19.01	17.05	3.16	4.12	3.64	0	0	0	0.4	0.5	0.45	0.1	0.1	0.1	0	0	0	0	0	0
A J1966-50	7.91	1.99	4.95	1.91	0.31	1.11	0	0	0	0.5	0.6	0.55	0	0	0	0	0	0	0	0	0
B 1966-50	3.72	13.2	8.46	0.26	1.27	0.765	0	0	0	0.2	0.8	0.5	0.1	0.1	0.1	0	0	0	0	0	0
A J1899-50+	8.59	8.1	8.345	1.64	1.42	1.53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C J1899-60	2.06	2.02	2.04	0.4	0.39	0.395	0.1	0.1	0.1	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0	0.05	0.1	0.1	0.1
A J1899-MG	-2.41	-2.12	-2.265	0.97	0.97	0.97	0	0	0	2.9	2	2.45	0.5	0.4	0.45	0.1	0.1	0.1	0.1	0.1	0.1
B J1899-MG	-3.48	-3.16	-3.32	-0.32	-0.46	-0.39	0	0	0	0.2	0.2	0.2	0.1	0.2	0.15	0.2	0.3	0.25	0.1	0.1	0.1
C J1899-MG1	-4.82	-4.63	-4.725	0.38	0.38	0.38	0	0	0	0.2	0.1	0.15	0.4	0.4	0.4	0	0	0	0	0	0

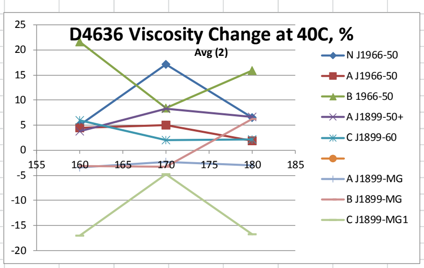
D4636 @ 180C	40 C Viscosity Change, %			TAN Change, mg KOH/g			Al weigh change, mg			Cu weight change, mg			Cd weight change, mg			Fe weight change, mg			Mg weight change, mg		
	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)
N J1966-50	2.83	10.22	6.525	0.37	2.02	1.195	0	0	0	0.7	0.9	0.8	0.1	0.1	0.1	0	0	0	0	0	0
A J1966-50	1.9	1.86	1.88	0.28	0.51	0.395	0	0	0	0.2	0.4	0.3	0.1	0	0.05	0	0	0	0	0	0
B 1966-50	21.41	10.48	15.945	2.25	0.86	1.555	0	0	0	0.9	0.6	0.75	0	0	0	0	0	0	0	0	0
A J1899-50+	1.58	11.63	6.605	0.49	1.91	1.2	0	0	0	0.2	0.6	0.4	0	0	0	0	0	0	0	0	0
C J1899-60	2.25	2.06	2.155	0.37	0.34	0.355	0	0.1	0.05	0.6	0.3	0.45	0.2	0.2	0.2	0.1	0	0.05	0.1	0.1	0.1
A J1899-MG	-3.54	-2.48	-3.01	1.15	1.03	1.09	0	0	0	2.7	2.6	2.65	0.2	0.2	0.2	0.4	0.3	0.35	0	0	0
B J1899-MG	11.68	0.91	6.295	4.45	3.54	3.995	0	0	0	0.5	0.3	0.4	0.2	0.2	0.2	0	0.1	0.05	0	0	0
C J1899-MG1	-17.87	-15.53	-16.7	3.36	3.5	3.43	0	0	0	1.1	1.3	1.2	17.8	15.3	16.55	0	0	0	0	0	0

D4636 @ 160C			Avg (2)				
	40C Vis	Tan	Al	Cu	Cd	Fe	Mg
N J1966-50	5.045	1.075	0	0.4	0.05	0	0
A J1966-50	4.43	1.415	0	0.3	0.25	0.15	0
B 1966-50	21.645	3.51	0	0.35	0.25	0.1	0.1
A J1899-50+	3.75	0.93	0	0.45	0.2	0	0.15
C J1899-60	5.97	1.38	0	0.3	0.1	0	0
A J1899-MG	-3.395	1.24	0.05	2.05	1.3	0.05	0
B J1899-MG	-3.16	1.205	0.05	0.4	0.55	0	0
C J1899-MG1	-17.01	5.32	0	0.5	23.55	0.4	0

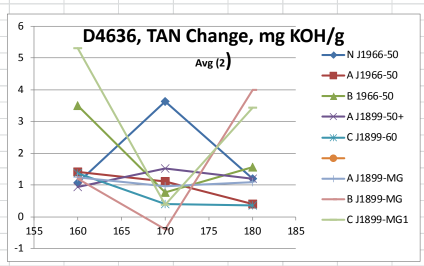
D4636 @ 170C			Avg (2)				
	40C Vis	Tan	Al	Cu	Cd	Fe	Mg
N J1966-50	17.05	3.64	0	0.45	0.1	0	0
A J1966-50	4.95	1.11	0	0.55	0	0	0
B 1966-50	8.46	0.765	0	0.5	0.1	0	0
A J1899-50+	8.345	1.53	0	0	0	0	0
C J1899-60	2.04	0.395	0.1	0.3	0.2	0.05	0.1
A J1899-MG	-2.265	0.97	0	2.45	0.45	0.1	0.1
B J1899-MG	-3.32	-0.39	0	0.2	0.15	0.25	0.1
C J1899-MG1	-4.725	0.38	0	0.15	0.4	0	0

D4636 @ 180C			Avg (2)				
	40C Vis	Tan	Al	Cu	Cd	Fe	Mg
N J1966-50	6.525	1.195	0	0.8	0.1	0	0
A J1966-50	1.88	0.395	0	0.3	0.05	0	0
B 1966-50	15.945	1.555	0	0.75	0	0	0
A J1899-50+	6.605	1.2	0	0.4	0	0	0
C J1899-60	2.155	0.355	0.05	0.45	0.2	0.05	0.1
A J1899-MG	-3.01	1.09	0	2.65	0.2	0.35	0
B J1899-MG	6.295	3.995	0	0.4	0.2	0.05	0
C J1899-MG1	-16.7	3.43	0	1.2	16.55	0	0

D4636	Viscosity Change		
Bath Temp, C	160	170	180
N J1966-50	5.045	17.05	6.525
A J1966-50	4.43	4.95	1.88
B 1966-50	21.645	8.46	15.945
A J1899-50+	3.75	8.345	6.605
C J1899-60	5.97	2.04	2.155
A J1899-MG	-3.395	-2.265	-3.01
B J1899-MG	-3.16	-3.32	6.295
C J1899-MG1	-17.01	-4.725	-16.7

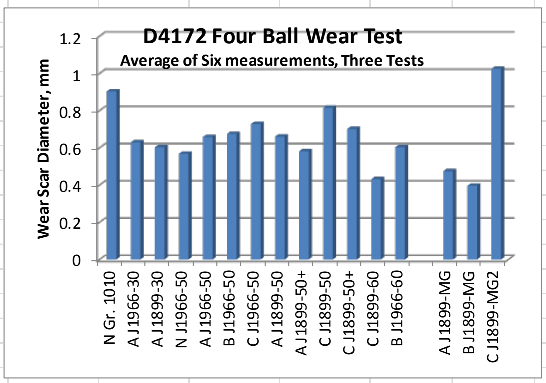


D4636	TAN Change		
Bath Temp, C	160	170	180
N J1966-50	1.075	3.64	1.195
A J1966-50	1.415	1.11	0.395
B 1966-50	3.51	0.765	1.555
A J1899-50+	0.93	1.53	1.2
C J1899-60	1.38	0.395	0.355
A J1899-MG	1.24	0.97	1.09
B J1899-MG	1.205	-0.39	3.995
C J1899-MG1	5.32	0.38	3.43



Note: Only three tests were run on each oil. Run1 / Run2 incicates the aveage wear scar on the 3 balls measured in two directions 90 degrees appart

Tab D4172		ASTM D4172, Four-Ball Wear Test							repeat	0.12			
		40 Kg	1200	60 minutes					Repro	0.28			
		Wear Scar Diameter, mm											
		Test 1		Test 2		Test 3							
Mfgr / Type	Avg (6)	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6		Std Dev	avg (4)	date run		
N Gr. 1010	0.90	0.91	0.91	0.82	0.82	0.98	0.98		0.07		10-Dec	15-Jan	15-Jan
A J1966-30	0.63	0.67	0.70	0.66	0.65	0.54	0.56		0.06		18-Jan	18-Jan	7-Feb
A J1899-30	0.60	0.59	0.58	0.72	0.73	0.49	0.51		0.10	???	18-Jan	25-Jan	7-Feb
N J1966-50	0.57	0.42	0.44	0.45	0.45	**0.84**	**0.81**		0.20	0.44	26-Nov	26-Nov	**7-Feb**
A J1966-50	0.66	0.60	0.61	0.72	0.74	0.64	0.64		0.06		10-Dec	15-Jan	7-Feb
B J1966-50	0.68	0.67	0.67	0.68	0.67	0.68	0.68		0.01		13-Nov	13-Nov	13-Nov
C J1966-50	0.73	0.63	0.63	0.58	0.59	**0.97**	**0.97**		0.19	0.6075	15-Jan	15-Jan	**11-Jan**
A J1899-50	0.66	0.71	0.73	0.66	0.62	0.61	0.63		0.05		25-Jan	25-Jan	25-Jan
A J1899-50+	0.58	0.54	0.54	0.58	0.56	0.64	0.63		0.04		15-Jan	15-Jan	15-Jan
C J1899-50	0.82	0.63	0.64	*0.44*	*0.43*	**1.40**	**1.35**		0.44	0.535	11-Jan	*11-Jan*	**11-Jan**
C J1899-50+	0.70	0.67	0.69	0.74	0.78	0.67	0.66		0.05		11-Jan	11-Jan	11-Jan
C J1899-60	0.43	0.57	0.57	0.38	0.38	0.35	0.34		0.11	0.3625	26-Nov	15-Jan	15-Jan
B J1966-60	0.60	0.66	0.67	0.64	0.64	0.50	0.51		0.08		13-Nov	13-Nov	15-Jan
A J1899-MG	0.48	0.56	0.55	*0.35*	*0.36*	0.52	0.51		0.09	0.535	18-Jan	*18-Jan*	18-Jan
B J1899-MG	0.40	0.35	0.35	0.39	0.40	0.44	0.45		0.04		13-Nov	16-Jan	16-Jan
C J1899-MG2	1.03	0.84	0.88	**1.34**	**1.39**	*0.86*	*0.84*		0.26	0.855	11-Jan	**11-Jan**	*11-Jan*



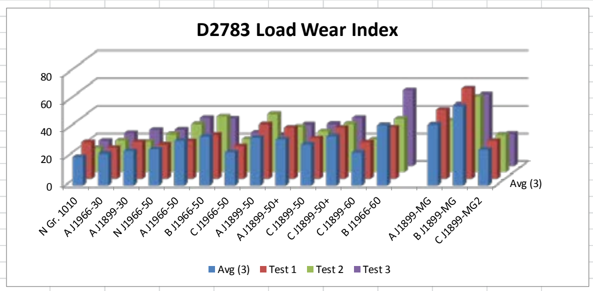
TAB D2783 page 1

Table X: ASTM D2783, Four-Ball Extreme Pressure Test — repeat: 1 incremental load
Weld Point, Kg — repro: 1 incremental load

Mfgr / Type	Avg (3)	Test 1	Test 2	Test 3
N Gr. 1010	271.7	315.0	250.0	250.0
A J1966-30	250.0	250.0	250.0	250.0
A J1899-30	250.0	250.0	250.0	250.0
N J1966-50	250.0	250.0	250.0	250.0
A J1966-50	271.7	250.0	250.0	315.0
B J1966-50	315.0	315.0	315.0	315.0
C J1966-50	250.0	250.0	250.0	250.0
A J1899-50	250.0	250.0	250.0	250.0
A J1899-50+	250.0	250.0	250.0	250.0
C J1899-50	250.0	250.0	250.0	250.0
C J1899-50+	250.0	250.0	250.0	250.0
C J1899-60	271.7	315.0	250.0	250.0
B J1966-60	271.7	250.0	250.0	315.0
A J1899-MG	315.0	315.0	315.0	315.0
B J1899-MG	315.0	315.0	315.0	315.0
C J1899-MG2	293.3	315.0	315.0	250.0

ASTM D2783, Four-Ball Extreme Pressure Test — repeat: 17% of mean
Load Wear Index — repro: 44% of mean

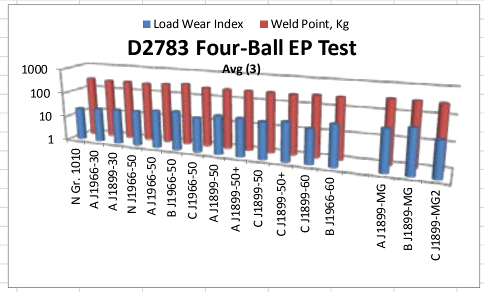
Mfgr / Type	Avg (3)	Test 1	Test 2	Test 3	Avg (2)	Test 1	Test 2	Test 3
N Gr. 1010	20.7	26.5	17.6	18.0	17.8	16-Nov	28-Feb	28-Feb
A J1966-30	23.0	22.6	22.9	23.4		18-Feb	18-Feb	18-Feb
A J1899-30	24.8	26.7	21.9	25.9		28-Feb	28-Feb	28-Feb
N J1966-50	26.1	24.8	27.5	26.1		28-Feb	28-Feb	28-Feb
A J1966-50	32.3	27.3	34.8	34.7		13-Feb	13-Feb	28-Feb
B J1966-50	35.5	31.8	40.5	34.1		13-Nov	13-Nov	13-Nov
C J1966-50	23.9	23.9	24.1	23.7		18-Feb	18-Feb	28-Feb
A J1899-50	34.5	39.4	42.1	22.1	40.8	28-Feb	28-Feb	28-Feb
A J1899-50+	33.3	37.1	33.0	29.7		28-Feb	28-Feb	28-Feb
C J1899-50	29.7	29.5	29.6	30.1		28-Feb	28-Feb	28-Feb
C J1899-50+	35.6	37.1	35.0	34.7		28-Feb	28-Feb	28-Feb
C J1899-60	23.7	26.4	23.8	20.8		13-Feb	13-Feb	13-Feb
B J1966-60	43.5	37.2	38.7	54.5	38.0	7-Feb	7-Feb	13-Feb
A J1899-MG	43.9	50.0	37.5	44.2	40.9	20-Feb	18-Feb	28-Feb
B J1899-MG	57.2	65.4	54.6	51.6	53.1	15-Nov	13-Feb	13-Feb
C J1899-MG2	25.8	27.5	27.0	23.0		28-Feb	28-Feb	28-Feb



Tab D2783 page 2

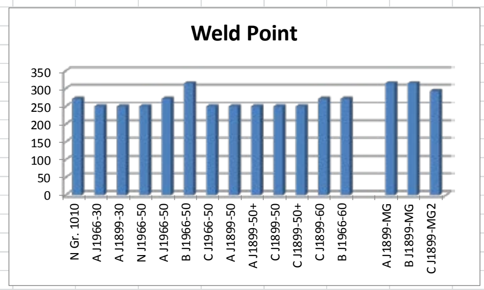
D2783

Mfgr / Type	ad Wear Inc	Veld Point, Kg
N Gr. 1010	20.7	271.7
A J1966-30	23.0	250.0
A J1899-30	24.8	250.0
N J1966-50	26.1	250.0
A J1966-50	32.3	271.7
B J1966-50	35.5	315.0
C J1966-50	23.9	250.0
A J1899-50	34.5	250.0
A J1899-50+	33.3	250.0
C J1899-50	29.7	250.0
C J1899-50+	35.6	250.0
C J1899-60	23.7	271.7
B J1966-60	43.5	271.7
A J1899-MG	43.9	315.0
B J1899-MG	57.2	315.0
C J1899-MG2	25.8	293.3



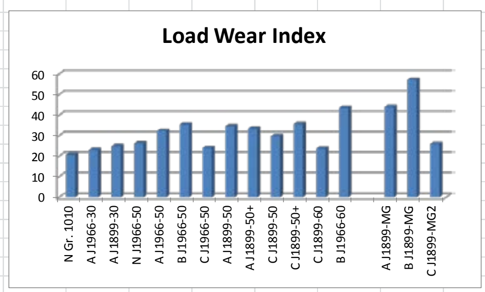
D2783

Mfgr / Type	Weld Point
N Gr. 1010	271.7
A J1966-30	250.0
A J1899-30	250.0
N J1966-50	250.0
A J1966-50	271.7
B J1966-50	315.0
C J1966-50	250.0
A J1899-50	250.0
A J1899-50+	250.0
C J1899-50	250.0
C J1899-50+	250.0
C J1899-60	271.7
B J1966-60	271.7
A J1899-MG	315.0
B J1899-MG	315.0
C J1899-MG2	293.3



D2783

Mfgr / Type	Load Wear Index
N Gr. 1010	20.7
A J1966-30	23.0
A J1899-30	24.8
N J1966-50	26.1
A J1966-50	32.3
B J1966-50	35.5
C J1966-50	23.9
A J1899-50	34.5
A J1899-50+	33.3
C J1899-50	29.7
C J1899-50+	35.6
C J1899-60	23.7
B J1966-60	43.5
A J1899-MG	43.9
B J1899-MG	57.2
C J1899-MG2	25.8



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APPENDIX B

TEST DATA

Table of Contents

ASTM D4636 Oxidation Performance Test

ASTM D4636 Results

D4636 @ 160C

	40 C Viscosity Change, %			TAN Change, mg KOH/g			EOT	Code	Code	Al weigh change, mg			Cu weight change, mg			Cd weight change, mg			Fe weight change, mg			Mg weight change, mg		
	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Date	Test 1	Test 2	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)
N J1966-50	2.13	7.96	5.045	0.32	1.83	1.075	10-Dec	201260oc1	201260oca	0	0	0	0.4	0.4	0.4	0.1	0	0.05	0	0	0	0	0	0
A J1966-50	1.08	7.78	4.43	0.35	2.48	1.415	8-Dec	201175oca	201175oc1	0	0	0	0.4	0.2	0.3	0.2	0.3	0.25	0.1	0.2	0.15	0	0	0
B 1966-50	20.5	22.79	21.645	3.08	3.94	3.51	10-Dec	201145oca	201145oc1	0	0	0	0.4	0.3	0.35	0.3	0.2	0.25	0.1	0.1	0.1	0	0.2	0.1
A J1899-50+	5.65	1.85	3.75	1.48	0.38	0.93	8-Dec	201176oc1	201176oca	0	0	0	0.6	0.3	0.45	0.2	0.2	0.2	0	0	0	0.1	0.2	0.15
C J1899-60	10.12	1.82	5.97	2.42	0.34	1.38	10-Dec	201161oc1	201161oca	0	0	0	0.4	0.2	0.3	0.1	0.1	0.1	0	0	0	0	0	0
A J1899-MG	-4.38	-2.41	-3.395	1.21	1.27	1.24	10-Dec	201177oc1	201177oca	0	0.1	0.05	3.1	1	2.05	1.2	1.4	1.3	0.1	0	0.05	0	0	0
B J1899-MG	-3.16	-3.16	-3.16	1.27	1.14	1.205	10-Dec	201167oc1	201167oca	0	0.1	0.05	0.7	0.1	0.4	0.9	0.2	0.55	0	0	0	0	0	0
C J1899-MG1	-19.96	-14.06	-17.01	3.71	6.93	5.32	10-Dec	201157oc1	201157oca	0	0	0	0.1	0.9	0.5	21.6	25.5	23.55	0.7	0.1	0.4	0	0	0

D4636 @ 170C

	40 C Viscosity Change, %			TAN Change, mg KOH/g			EOT	Code	Code	Al weigh change, mg			Cu weight change, mg			Cd weight change, mg			Fe weight change, mg			Mg weight change, mg		
	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Date	Test 1	Test 2	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)
N J1966-50	15.09	19.01	17.05	3.16	4.12	3.64	3-Jan	201260ocb	201260occ	0	0	0	0.4	0.5	0.45	0.1	0.1	0.1	0	0	0	0	0	0
A J1966-50	7.91	1.99	4.95	1.91	0.31	1.11	22-Dec	201175occ	201175ocb	0	0	0	0.5	0.6	0.55	0	0	0	0	0	0	0	0	0
B 1966-50	3.72	13.2	8.46	0.26	1.27	0.765	14-Dec	201145ocb	201145occ	0	0	0	0.2	0.8	0.5	0.1	0.1	0.1	0	0	0	0	0	0
A J1899-50+	8.59	8.1	8.345	1.64	1.42	1.53	22-Dec	201176ocb	201176occ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C J1899-60	2.06	2.02	2.04	0.4	0.39	0.395	21-Dec	201161ocb	201161occ	0.1	0.1	0.1	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0	0.05	0.1	0.1	0.1
A J1899-MG	-2.41	-2.12	-2.265	0.97	0.97	0.97	Jan 13 & 3	201177ocb	201177occ	0	0	0	2.9	2	2.45	0.5	0.4	0.45	0.1	0.1	0.1	0.1	0.1	0.1
B J1899-MG	-3.48	-3.16	-3.32	-0.32	-0.46	-0.39	21-Dec	201167occ	201167ocb	0	0	0	0.2	0.2	0.2	0.1	0.2	0.15	0.2	0.3	0.25	0.1	0.1	0.1
C J1899-MG1	-4.82	-4.63	-4.725	0.38	0.38	0.38	14-Dec	201157occ	201157ocb	0	0	0	0.2	0.1	0.15	0.4	0.4	0.4	0	0	0	0	0	0

D4636 @ 180C

	40 C Viscosity Change, %			TAN Change, mg KOH/g			EOT	Code	Code	Al weigh change, mg			Cu weight change, mg			Cd weight change, mg			Fe weight change, mg			Mg weight change, mg		
	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Date	Test 1	Test 2	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)	Test 1	Test 2	Avg (2)
N J1966-50	2.83	10.22	6.525	0.37	2.02	1.195	3-Jan	201260ocd	201260oce	0	0	0	0.7	0.9	0.8	0.1	0.1	0.1	0	0	0	0	0	0
A J1966-50	1.9	1.86	1.88	0.28	0.51	0.395	22-Dec	201175oce	201175ocd	0	0	0	0.2	0.4	0.3	0.1	0	0.05	0	0	0	0	0	0
B 1966-50	21.41	10.48	15.945	2.25	0.86	1.555	14-Dec	201145ocd	201145oce	0	0	0	0.9	0.6	0.75	0	0	0	0	0	0	0	0	0
A J1899-50+	1.58	11.63	6.605	0.49	1.91	1.2	22-Dec	201176ocd	201176oce	0	0	0	0.2	0.6	0.4	0	0	0	0	0	0	0	0	0
C J1899-60	2.25	2.06	2.155	0.37	0.34	0.355	21-Dec	201161ocd	201161oce	0	0.1	0.05	0.6	0.3	0.45	0.2	0.2	0.2	0.1	0	0.05	0.1	0.1	0.1
A J1899-MG	-3.54	-2.48	-3.01	1.15	1.03	1.09	3-Jan	201177ocd	201177oce	0	0	0	2.7	2.6	2.65	0.2	0.2	0.2	0.4	0.3	0.35	0	0	0
B J1899-MG	11.68	0.91	6.295	4.45	3.54	3.995	21-Dec	201167oce	201167ocd	0	0	0	0.5	0.3	0.4	0.2	0.2	0.2	0	0.1	0.05	0	0	0
C J1899-MG1	-17.87	-15.53	-16.7	3.36	3.5	3.43	17-Dec	201157ocd	201157oce	0	0	0	1.1	1.3	1.2	17.8	15.3	16.55	0	0	0	0	0	0

D4636 @ 160C Avg (2)

	40C Vis	Tan	Al	Cu	Cd	Fe	Mg
N J1966-50	5.045	1.075	0	0.4	0.05	0	0
A J1966-50	4.43	1.415	0	0.3	0.25	0.15	0
B 1966-50	21.645	3.51	0	0.35	0.25	0.1	0.1
A J1899-50+	3.75	0.93	0	0.45	0.2	0	0.15
C J1899-60	5.97	1.38	0	0.3	0.1	0	0
A J1899-MG	-3.395	1.24	0.05	2.05	1.3	0.05	0
B J1899-MG	-3.16	1.205	0.05	0.4	0.55	0	0
C J1899-MG1	-17.01	5.32	0	0.5	23.55	0.4	0

D4636 @ 180C Avg (2)

	40C Vis	Tan	Al	Cu	Cd	Fe	Mg
N J1966-50	6.525	1.195	0	0.8	0.1	0	0
A J1966-50	1.88	0.395	0	0.3	0.05	0	0
B 1966-50	15.945	1.555	0	0.75	0	0	0
A J1899-50+	6.605	1.2	0	0.4	0	0	0
C J1899-60	2.155	0.355	0.05	0.45	0.2	0.05	0.1
A J1899-MG	-3.01	1.09	0	2.65	0.2	0.35	0
B J1899-MG	6.295	3.995	0	0.4	0.2	0.05	0
C J1899-MG1	-16.7	3.43	0	1.2	16.55	0	0

D4636 Viscosity Change

Bath Temp, C	160	170	180
N J1966-50	5.045	17.05	6.525
A J1966-50	4.43	4.95	1.88
B 1966-50	21.645	8.46	15.945
A J1899-50+	3.75	8.345	6.605
C J1899-60	5.97	2.04	2.155
A J1899-MG	-3.395	-2.265	-3.01
B J1899-MG	-3.16	-3.32	6.295
C J1899-MG1	-17.01	-4.725	-16.7

D4636 @ 170C Avg (2)

	40C Vis	Tan	Al	Cu	Cd	Fe	Mg
N J1966-50	17.05	3.64	0	0.45	0.1	0	0
A J1966-50	4.95	1.11	0	0.55	0	0	0
B 1966-50	8.46	0.765	0	0.5	0.1	0	0
A J1899-50+	8.345	1.53	0	0	0	0	0
C J1899-60	2.04	0.395	0.1	0.3	0.2	0.05	0.1
A J1899-MG	-2.265	0.97	0	2.45	0.45	0.1	0.1
B J1899-MG	-3.32	-0.39	0	0.2	0.15	0.25	0.1
C J1899-MG1	-4.725	0.38	0	0.15	0.4	0	0

D4636 TAN Change

Bath Temp, C	160	170	180
N J1966-50	1.075	3.64	1.195
A J1966-50	1.415	1.11	0.395
B 1966-50	3.51	0.765	1.555
A J1899-50+	0.93	1.53	1.2
C J1899-60	1.38	0.395	0.355
A J1899-MG	1.24	0.97	1.09
B J1899-MG	1.205	-0.39	3.995
C J1899-MG1	5.32	0.38	3.43

ASTM D4172 Four Ball Wear Test

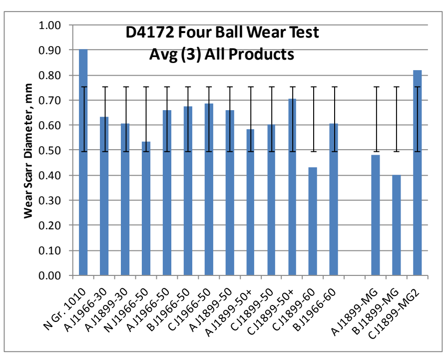
mm | 1st run: not in average or SD | re-run: 11-May

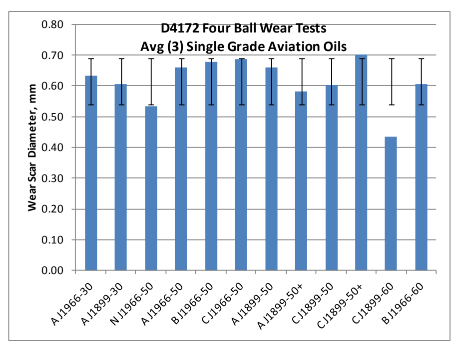
ASTM D4172, Four-Ball Wear Test — repeat 0.12 — Repro 0.28
40 Kg — 1200 rpm — 60 minutes
Wear Scar Diameter, mm

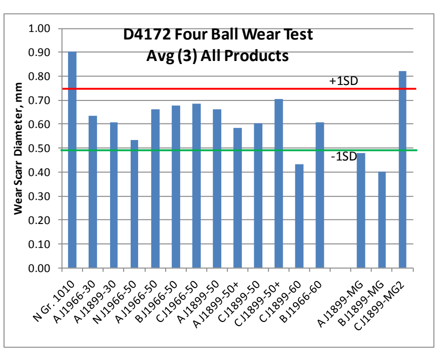
Mfgr / Type	Avg (3)	Test 1	Test 2	Test 3		Std Dev		date run			
N Gr. 1010	0.90	0.91	0.82	0.98		0.08		10-Dec	15-Jan	15-Jan	
A J1966-30	0.63	0.69	0.66	0.55		0.07		18-Jan	18-Jan	7-Feb	
A J1899-30	0.61	0.59	0.73	0.50		0.12		18-Jan	25-Jan	7-Feb	
N J1966-50	0.53	0.43	0.45	0.72	0.83	0.16		26-Nov	26-Nov	11-May	7-Feb
A J1966-50	0.66	0.61	0.73	0.64		0.06		10-Dec	15-Jan	7-Feb	
B J1966-50	0.68	0.67	0.68	0.68		0.01		13-Nov	13-Nov	13-Nov	
C J1966-50	0.69	0.63	0.59	0.84	0.97	0.13		15-Jan	15-Jan	11-May	11-Jan
A J1899-50	0.66	0.72	0.64	0.62		0.05		25-Jan	25-Jan	25-Jan	
A J1899-50+	0.58	0.54	0.57	0.64		0.05		15-Jan	15-Jan	15-Jan	
C J1899-50	0.60	0.64	0.44	0.73	1.38	0.15		11-Jan	*11-Jan*	11-May	11-Jan
C J1899-50+	0.70	0.68	0.76	0.67		0.05		11-Jan	11-Jan	11-Jan	
C J1899-60	0.43	0.57	0.38	0.35		0.12		26-Nov	15-Jan	15-Jan	
B J1966-60	0.61	0.67	0.64	0.51		0.09		13-Nov	13-Nov	15-Jan	
A J1899-MG	0.48	0.56	0.36	0.52		0.11		18-Jan	*18-Jan*	18-Jan	
B J1899-MG	0.40	0.35	0.40	0.45		0.05		13-Nov	16-Jan	16-Jan	
C J1899-MG2	0.82	0.86	0.75	0.85	1.37	0.28		11-Jan	11-May	11-Jan	11-Jan

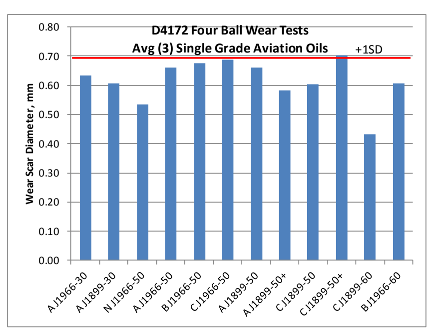
ASTM D4172, Four-Ball Wear Test — repeat 0.12 — Repro 0.28
40 Kg — 1750 rpm — 60 minutes
Wear Scar Diameter, mm

Mfgr / Type	Avg (6)	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6		Std Dev	avg (4)	date run		
N Gr. 1010	0.90	0.91	0.91	0.82	0.82	0.98	0.98		0.07		10-Dec	15-Jan	15-Jan
A J1966-30	0.63	0.67	0.70	0.66	0.65	0.54	0.56		0.06		18-Jan	18-Jan	7-Feb
A J1899-30	0.60	0.59	0.58	0.72	0.73	0.49	0.51		0.10	???	18-Jan	25-Jan	7-Feb
N J1966-50	0.57	0.42	0.44	0.45	0.45	**0.84**	**0.81**		0.20	0.44	26-Nov	26-Nov	**7-Feb**
A J1966-50	0.66	0.60	0.61	0.72	0.74	0.64	0.64		0.06		10-Dec	15-Jan	7-Feb
B J1966-50	0.68	0.67	0.67	0.68	0.67	0.68	0.68		0.01		13-Nov	13-Nov	13-Nov
C J1966-50	0.73	0.63	0.63	0.58	0.59	**0.97**	**0.97**		0.19	0.6075	15-Jan	15-Jan	**11-Jan**
A J1899-50	0.66	0.71	0.73	0.66	0.62	0.61	0.63		0.05		25-Jan	25-Jan	25-Jan
A J1899-50+	0.58	0.54	0.54	0.58	0.56	0.64	0.63		0.04		15-Jan	15-Jan	15-Jan
C J1899-50	0.82	0.63	0.64	*0.44*	*0.43*	**1.40**	**1.35**		0.44	0.535	11-Jan	*11-Jan*	**11-Jan**
C J1899-50+	0.70	0.67	0.69	0.74	0.78	0.67	0.66		0.05		11-Jan	11-Jan	11-Jan
C J1899-60	0.43	0.57	0.57	0.38	0.38	0.35	0.34		0.11	0.3625	26-Nov	15-Jan	15-Jan
B J1966-60	0.60	0.66	0.67	0.64	0.64	0.50	0.51		0.08		13-Nov	13-Nov	15-Jan
A J1899-MG	0.48	0.56	0.55	*0.35*	*0.36*	0.52	0.51		0.09	0.535	18-Jan	*18-Jan*	18-Jan
B J1899-MG	0.40	0.35	0.35	0.39	0.40	0.44	0.45		0.04		13-Nov	16-Jan	16-Jan
C J1899-MG2	1.03	0.84	0.88	**1.34**	**1.39**	*0.86*	*0.84*		0.26	0.855	11-Jan	**11-Jan**	*11-Jan*









ASTM D2783 Four Ball Extreme Pressure Test

ASTM D2783, Four-Ball Extreme Pressure Test
Weld Point, Kg

repeat: 1 incremental load
repro: 1 incremental load

Mfgr / Type	Avg (3)	Test 1	Test 2	Test 3
N Gr. 1010	271.7	315.0	250.0	250.0
A J1966-30	250.0	250.0	250.0	250.0
A J1899-30	250.0	250.0	250.0	250.0
N J1966-50	250.0	250.0	250.0	250.0
A J1966-50	271.7	250.0	250.0	315.0
B J1966-50	315.0	315.0	315.0	315.0
C J1966-50	250.0	250.0	250.0	250.0
A J1899-50	250.0	250.0	250.0	250.0
A J1899-50+	250.0	250.0	250.0	250.0
C J1899-50	250.0	250.0	250.0	250.0
C J1899-50+	250.0	250.0	250.0	250.0
C J1899-60	271.7	315.0	250.0	250.0
B J1966-60	271.7	250.0	250.0	315.0
A J1899-MG	315.0	315.0	315.0	315.0
B J1899-MG	315.0	315.0	315.0	315.0
C J1899-MG2	293.3	315.0	315.0	250.0

ASTM D2783, Four-Ball Extreme Pressure Test
Load Wear Index

repeat: 17% of mean
repro: 44% of mean

Mfgr / Type	Avg (3)	Test 1	Test 2	Test 3	Avg (2)	Test 1	Test 2	Test 3
N Gr. 1010	20.7	26.5	17.6	18.0	17.8	16-Nov	28-Feb	28-Feb
A J1966-30	23.0	22.6	22.9	23.4		18-Feb	18-Feb	18-Feb
A J1899-30	24.8	26.7	21.9	25.9		28-Feb	28-Feb	28-Feb
N J1966-50	26.1	24.8	27.5	26.1		28-Feb	28-Feb	28-Feb
A J1966-50	32.3	27.3	34.8	34.7		13-Feb	13-Feb	28-Feb
B J1966-50	35.5	31.8	40.5	34.1		13-Nov	13-Nov	13-Nov
C J1966-50	23.9	23.9	24.1	23.7		18-Feb	18-Feb	28-Feb
A J1899-50	34.5	39.4	42.1	22.1	40.8	28-Feb	28-Feb	**28-Feb**
A J1899-50+	33.3	37.1	33.0	29.7		28-Feb	28-Feb	28-Feb
C J1899-50	29.7	29.5	29.6	30.1		28-Feb	28-Feb	28-Feb
C J1899-50+	35.6	37.1	35.0	34.7		28-Feb	28-Feb	28-Feb
C J1899-60	23.7	26.4	23.8	20.8		13-Feb	13-Feb	13-Feb
B J1966-60	43.5	37.2	38.7	54.5	38.0	7-Feb	7-Feb	**13-Feb**
A J1899-MG	43.9	50.0	37.5	44.2	40.9	**20-Feb**	18-Feb	28-Feb
B J1899-MG	57.2	65.4	54.6	51.6	53.1	**15-Nov**	13-Feb	13-Feb
C J1899-MG2	25.8	27.5	27.0	23.0		28-Feb	28-Feb	28-Feb

D2783

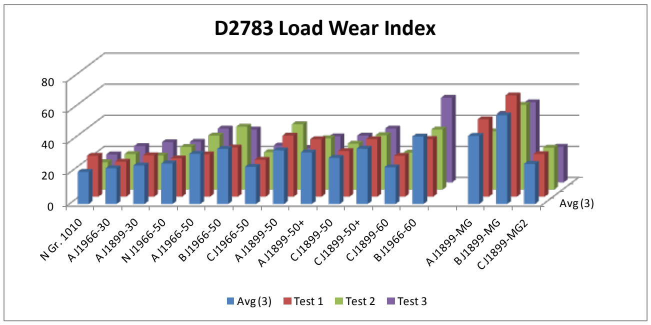
Mfgr / Type	Load Wear Index	Weld Point, Kg
N Gr. 1010	20.7	271.7
A J1966-30	23.0	250.0
A J1899-30	24.8	250.0
N J1966-50	26.1	250.0
A J1966-50	32.3	271.7
B J1966-50	35.5	315.0
C J1966-50	23.9	250.0
A J1899-50	34.5	250.0
A J1899-50+	33.3	250.0
C J1899-50	29.7	250.0
C J1899-50+	35.6	250.0
C J1899-60	23.7	271.7
B J1966-60	43.5	271.7
A J1899-MG	43.9	315.0
B J1899-MG	57.2	315.0
C J1899-MG2	25.8	293.3

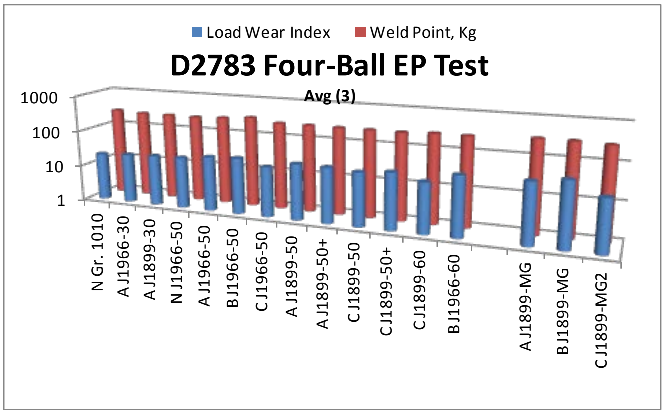
D2783

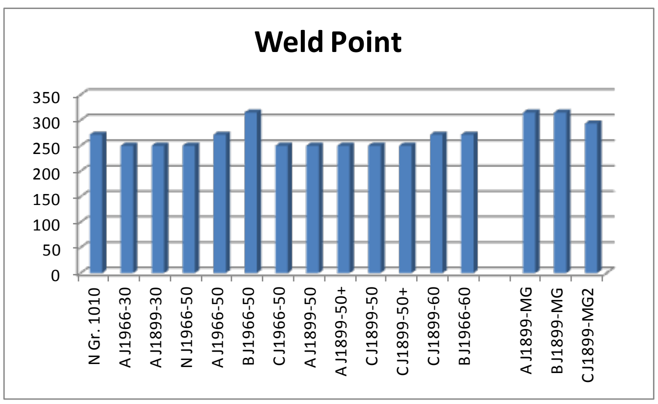
	Mfgr / Type	Weld Point
MIL-L-6081	N Gr. 1010	271.7
AS 65	A J1966-30	250.0
AS W65	A J1899-30	250.0
N cat AS100	N J1966-50	250.0
AS 100	A J1966-50	271.7
Ex Av 100	B J1966-50	315.0
Phil Ref #50	C J1966-50	250.0
AS W100	A J1899-50	250.0
AS W100+	A J1899-50+	250.0
Type A 100AD	C J1899-50	250.0
Type A 100AW	C J1899-50+	250.0
Type A 120	C J1899-60	271.7
Ex Av 120	B J1966-60	271.7
AS 15W50	A J1899-MG	315.0
Elite 20W50	B J1899-MG	315.0
X/C 25W60	C J1899-MG2	293.3

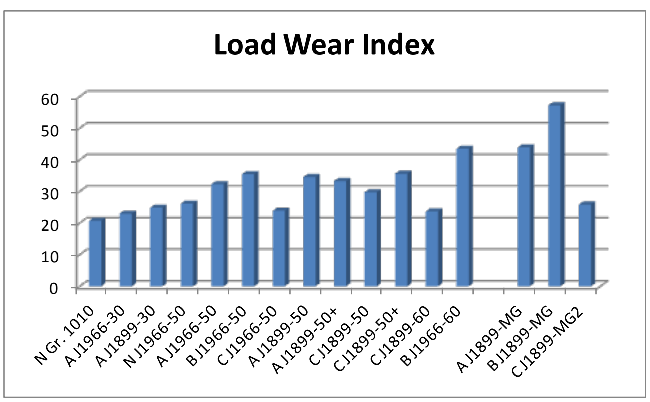
D2783

	Mfgr / Type	Load Wear Index
MIL-L-6081	N Gr. 1010	20.7
AS 65	A J1966-30	23.0
AS W65	A J1899-30	24.8
N cat AS100	N J1966-50	26.1
AS 100	A J1966-50	32.3
Ex Av 100	B J1966-50	35.5
Phil Ref #50	C J1966-50	23.9
AS W100	A J1899-50	34.5
AS W100+	A J1899-50+	33.3
Type A 100AD	C J1899-50	29.7
Type A 100AW	C J1899-50+	35.6
Type A 120	C J1899-60	23.7
Ex Av 120	B J1966-60	43.5
AS 15W50	A J1899-MG	43.9
Elite 20W50	B J1899-MG	57.2
X/C 25W60	C J1899-MG2	25.8


D2783 Load Wear Index
Avg (3)
Test 1
Test 2
Test 3


Load Wear Index
Weld Point, Kg
D2783 Four-Ball EP Test
Avg (3)


Weld Point


Load Wear Index

ASTM D4636 Oxidation Performance Test, Procedure 2

4/11/2012 **ASTM D4636, Procedure 2, Development Tests**

	J1966, SAE 50			J1966, SAE 50			J1966, SAE 50			J1966, SAE 50		
	165 C	165 C	Avg (1)	170 C	170 C	Avg (2)	175 C	175 C	Avg (2)	180 C	180 C	Avg (1)
40 C Viscosity Change, %		18.99	18.99	34.35	32.26	33.31	37.84	36.88	37.36		55.7	55.7
TAN Change, mgKOH/g		2.08	2.08	2.56	2.47	2.52	2.48	2.57	2.53		4.16	4.16
Metal Weight Change, mg												
Fe		0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01		0.01	0.01
Ag		-0.05	-0.05	-0.05	-0.06	-0.06	-0.06	-0.05	-0.06		-0.05	-0.05
Al		0.00	0.00	-0.01	0.00	-0.01	-0.01	0.00	-0.01		0	0
Mg		0.01	0.01	0.00	0.03	0.02	0.02	-0.01	0.01		0.01	0.01
Cu		-0.26	-0.26	-0.33	-0.30	-0.32	-0.25	-0.29	-0.27		-0.27	-0.27

	J1899, SAE 50			J1899, SAE 50			J1899, SAE 50			J1899, SAE 50		
	165 C	165 C	Avg (2)	170 C	170 C	Avg (2)	175 C	175 C	Avg (2)	180 C	180 C	Avg (1)
40 C Viscosity Change, %	22.85	18.49	20.67	33.35	31.92	32.64	35.76	35.81	35.79		40.83	40.83
TAN Change, mgKOH/g	2.59	2.25	2.42	2.64	2.61	2.63	2.77	3.02	2.90		3.65	3.65
Metal Weight Change, mg												
Fe	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01		0	0
Ag	-0.04	-0.03	-0.04	-0.02	-0.02	-0.02	-0.02	-0.03	-0.03		-0.02	-0.02
Al	-0.01	0.00	-0.01	0.01	-0.01	0.00	0.00	-0.01	-0.01		-0.01	-0.01
Mg	0.00	0.02	0.01	0.02	0.01	0.02	0.00	0.00	0.00		0.02	0.02
Cu	-0.12	-0.10	-0.11	-0.14	-0.15	-0.15	-0.24	-0.17	-0.21		-0.2	-0.2

Test Temperature	J1966	J1899
165	18.99	20.67
170	33.31	32.64
175	37.36	35.79
180	55.7	40.83

	J1966, SAE 50
	165 C
40 C Viscosity Change, %	31.85
TAN Change, mgKOH/g	3.14
Metal Weight Change, mg	
Fe	0.02
Ag	-0.06
Al	0.02
Mg	1.84
Cu	-1.89
	VOID

Isuspect two coupons were mixed pre and post test

ASTM D2272 Oxidation Stability of Steam Turbine Oils

ASTM D2272	Test 1	Test 2	Test 3	Test 4	Avg (4)
N Gr. 1010	137	131	132	128	132
B J1966-50	106	108	87	91	98
N J1966 50	200	205	175	175	189
A J1966-50	114	143	138	113	127
A J1899-50+	145	149	148	144	147
C J1899-60	104	102	112	105	106
A J1899-MG	447	492	503	507	487
B J1899-MG	421	431	416	447	429
C J1899-MG1	83	99	96	98	94

	Sulfur. %	
	by mfgr	by Pax
N Gr. 1010		0.01
B J1966-50	0.69	0.78
N J1966 50		0.3
A J1966-50	0.46	0.45
A J1899-50+	0.41	0.44
C J1899-60	0.16	0.14
A J1899-MG	0.2	0.21
B J1899-MG	0.44	0.56
C J1899-MG1	0.13	0.16

ASTM D5182 Scuffing Load Capacity of Oils by FZG Visual Method

ASTM D5182

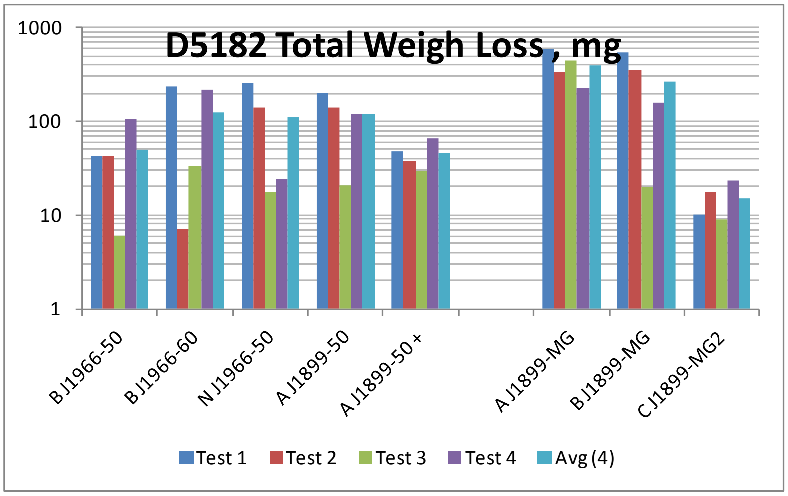
	Failure Load Stage				
Mfgr / Type	Test 1	Test 2	Test 3	Test 4	Avg (4)
B J1966-50	7	8	7	8	7.5
B J1966-60	9	8	8	9	8.5
N J1966-50	9	8	6	7	7.5
A J1899-50	9	8	8	8	8.25
A J1899-50 +	10	10	10	10	10
A J1899-MG	12	11	11	10	11
B J1899-MG	12	12	13	11	12
C J1899-MG2	9	9	9	8	8.75

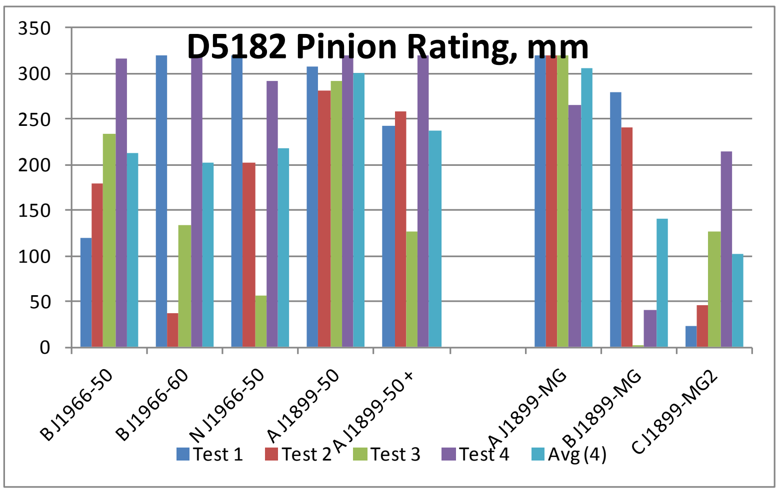
The test was terminated when no failure had occurred by the end of LS 12
for calculation purposes this was then considered to be a LS 13 failure

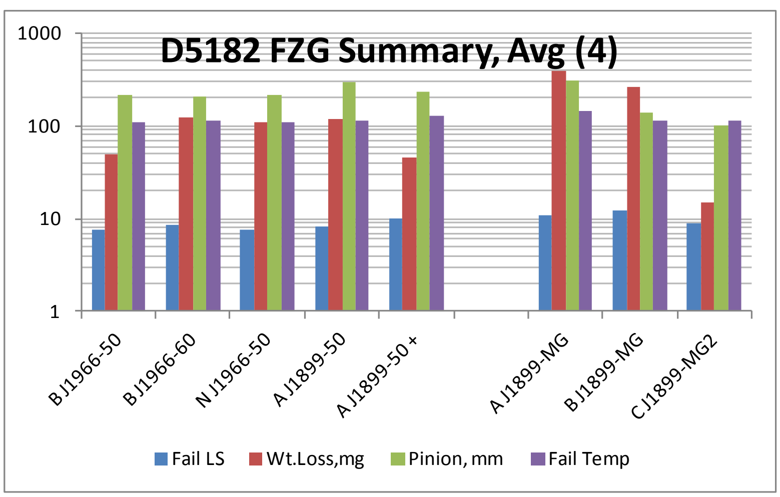
D5182	Total Weight Loss, mg				
Mfgr / Type	Test 1	Test 2	Test 3	Test 4	Avg (4)
B J1966-50	42	42	6	108	49.5
B J1966-60	233	7	33	221	123.5
N J1966-50	251	141	18	24	108.5
A J1899-50	199	139	21	121	120
A J1899-50 +	48	38	30	66	45.5
A J1899-MG	588	333	441	226	397
B J1899-MG	535	346	20	159	265
C J1899-MG2	10	18	9	23	15

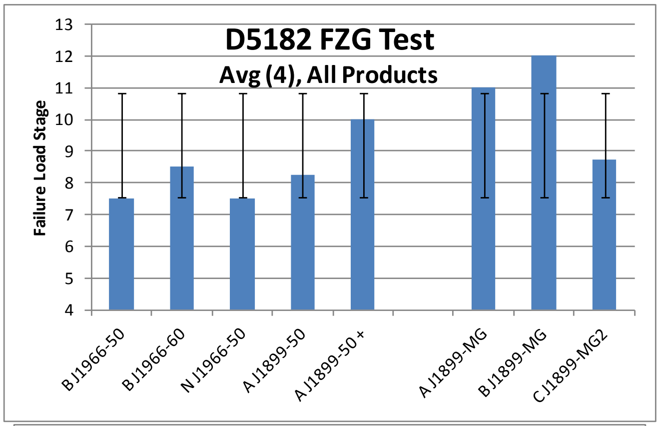
D5182	Pinion Rating				
Mfgr / Type	Test 1	Test 2	Test 3	Test 4	Avg (4)
B J1966-50	120	180	234	316	212.5
B J1966-60	320	38	134	320	203
N J1966-50	320	202	56	292	217.5
A J1899-50	308	282	292	320	300.5
A J1899-50 +	242	258	126	320	236.5
A J1899-MG	320	320	320	266	306.5
B J1899-MG	280	240	1	40	140.25
C J1899-MG2	24	46	126	214	102.5

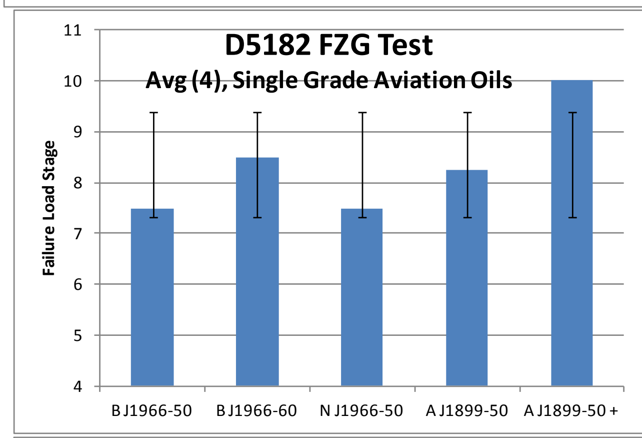
D5182				
Mfgr / Type	Fail LS	Wt.Loss,mg	Pinion, mm	Fail Temp
B J1966-50	7.5	49.5	212.5	109
B J1966-60	8.5	123.5	203	115
N J1966-50	7.5	108.5	217.5	109
A J1899-50	8.25	120	300.5	114
A J1899-50 +	10	45.5	236.5	130
A J1899-MG	11	397	306.5	143
B J1899-MG	12	265	140.25	115
C J1899-MG2	8.75	15	102.5	116

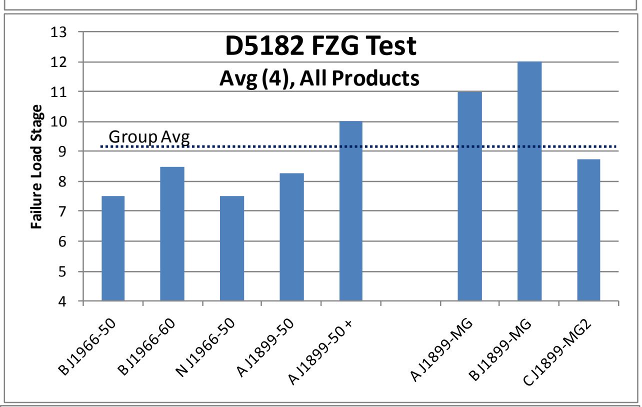

D5182 Total Weigh Loss, mg
1000
100
10
1
B J1966-50
B J1966-60
N J1966-50
A J1899-50
A J1899-50 +
A J1899-MG
B J1899-MG
C J1899-MG2
Test 1
Test 2
Test 3
Test 4
Avg (4)

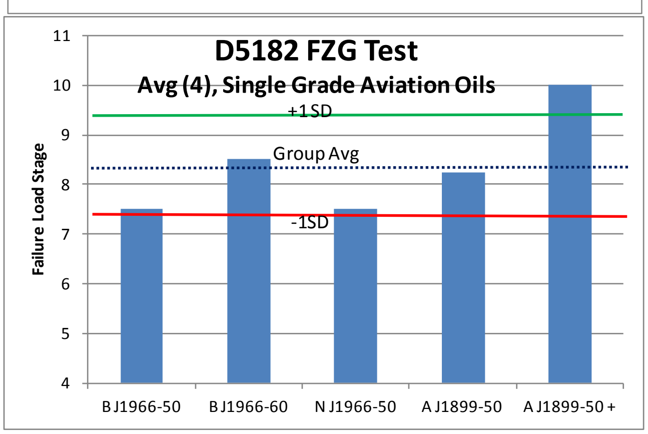

D5182 Pinion Rating, mm
350
300
250
200
150
100
50
0
B J1966-50
B J1966-60
N J1966-50
A J1899-50
A J1899-50 +
A J1899-MG
B J1899-MG
C J1899-MG2
Test 1
Test 2
Test 3
Test 4
Avg (4)


D5182 FZG Summary, Avg (4)
1000
100
10
1
B J1966-50
B J1966-60
N J1966-50
A J1899-50
A J1899-50 +
A J1899-MG
B J1899-MG
C J1899-MG2
Fail LS
Wt.Loss,mg
Pinion, mm
Fail Temp


D5182 FZG Test
Avg (4), All Products
Failure Load Stage
13
12
11
10
9
8
7
6
5
4
B J1966-50
B J1966-60
N J1966-50
A J1899-50
A J1899-50 +
A J1899-MG
B J1899-MG
C J1899-MG2


D5182 FZG Test
Avg (4), Single Grade Aviation Oils
Failure Load Stage
11
10
9
8
7
6
5
4
B J1966-50
B J1966-60
N J1966-50
A J1899-50
A J1899-50 +


D5182 FZG Test
Avg (4), All Products
Group Avg
Failure Load Stage
13
12
11
10
9
8
7
6
5
4
B J1966-50
B J1966-60
N J1966-50
A J1899-50
A J1899-50 +
A J1899-MG
B J1899-MG
C J1899-MG2


D5182 FZG Test
Avg (4), Single Grade Aviation Oils
+1SD
Group Avg
-1SD
Failure Load Stage
11
10
9
8
7
6
5
4
B J1966-50
B J1966-60
N J1966-50
A J1899-50
A J1899-50 +

ASTM D943 Oxidation Characteristics of Inhibited Mineral Oils

Run ASTM D943: Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils on 5 oils with two tests apiece.												
Test:	ASTM D943											
# of Oils	5											
#Tests/oil	2	**Test Hours (results in mg KOH/g)**							**Sample Date**			
		500h	668h	836h	1004h	1172 (bonus time)		500 hr	668hr	836hr	1004hr	"Lifetime"
B J1966-50		0.59	0.99	1.2	1.62	2.34		1/3/2013	1/10/2013	1/17/2013	1/24/2013	
B J1966-50		0.74	1.74	1.62	2.67			1/15/2013	1/22/2013	1/25/2013	2/2/2013	897
N J1966-50		0.5	1.22	1.05	1.41							
N J1966-50		0.62	1.09	1.09	1.65							
A J1966-50		0.58	0.92	1.14	0.95							
A J1966-50		0.54	1.45	1.07	1.15							
A J1899-50+		0.27	0.55	0.53	1.56							
A J1899-50+		0.31	0.55	0.57	0.77							
C J1899-60		0.88	1.76	1.45	2.33			1/16/2013	1/22/2013	1/25/2013	2/2/2013	941
C J1899-60		3.06	15.4	failed test	?							
C J1899-60		3.33	15.8	failed test	?							

Physical and Chemical Property Test Data

Physical and Chemical Property Data

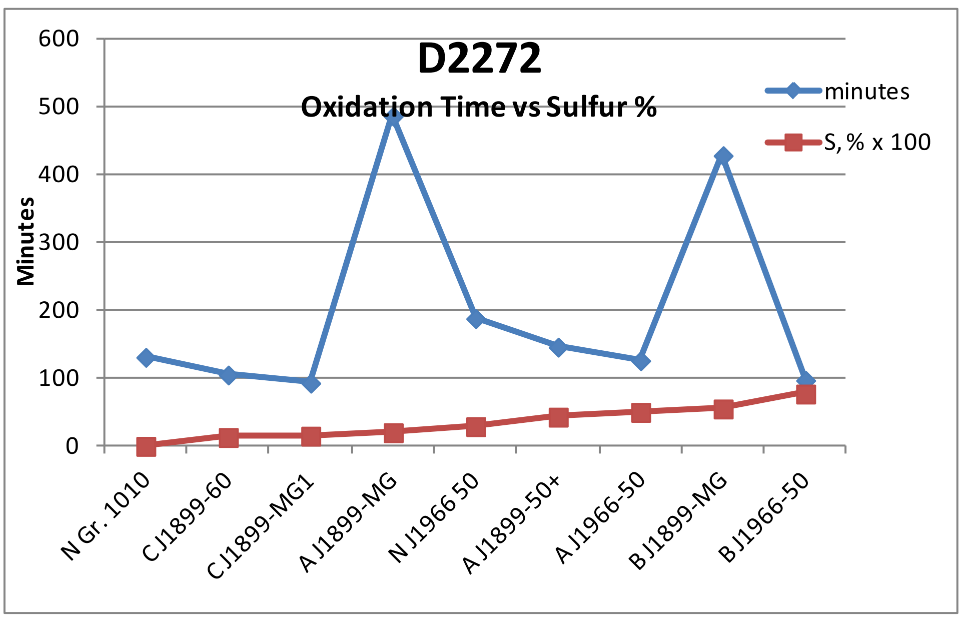
Standard SAE J1966 / J1899 Data On Sample Products

Man.	SAE Standard	Grade	NAVAIR Code Number	Navy VIS @ 40 C	Mfgr. VIS @ 40 C	Navy VIS @ 100 C	Mfgr. VIS @ 100 C	Navy Viscosity Index	Mfgr. Viscosity Index	Navy TAN *	Mfgr. TAN *	Navy Sulfur % *	Mfgr. Sulfur % *	Navy API @ 60 F	Mfgr. API @ 60 F	Mfgr. D-2273 trace sediment*	Mfgr. D-482 Ash content*	Information Items: Navy DSC Breakpoint Temp.	Information Items: Navy Sp. Heat	Information Items: Qual Value Dxxxx HTHS Vis 150C, cP
A	SAE Standard	Grade	NAVAIR Code Number																	
	J1966	SAE 30	12214-04943	98.76	98.43	11.44	11.48	103	x	0	0.03	0.33	0.38	29.38	29.4	0	0	327.67		3.4
		SAE 50	12214-04944	231	230.01	20.16	20.27	101	x	0.16	0.05	0.45	0.46	28.23	28.1	0	0.002	251.89	y	5.1
	J1899	SAE 30	12214-04949	92.34	91.91	12.09	12.14	123	125	0	0.03	0.31	0.33	29.6	29.6	0	0	326.14		
		SAE 50	12214-04950	198.1	198	19.91	19.89	116	117	0	0.04	0.51	0.48	28.52	x	0	0	323.85	y	4.5
		SAE 50+	12214-04948	183.8	186.65	19.19	19.5	119	120	0.02	0.03	0.44	0.41	27.86	28	0	0	328.09		4.6
		SAE MG	12214-04951	141.2	140.8	19.37	19.36	157	157	0.35	0.04	0.21	0.2	33.02	33	0	0.004	326.35	y	4.6
B	SAE Standard	Grade	NAVAIR Code Number																	
	J1966	SAE 50	12214-04945	219.9	218.1	19.03	19	97	x	0	0.02	0.78	0.69	26.97	26.7	0.001	0.001	256.82	y	5.1
		SAE 60	12214-04946	325.3	323.4	24.3	24.3	95	x	0.04	0	0.78	0.61	26.3	26.1	0	0.002	399.47		6.1
	J1899	SAE MG	12214-04952	185.3	183.33	20.7	20.6	131	132	1.06	1	0.56	0.44	29.53	29.6	0.002	x	397.74	y	4.99
C	SAE Standard	Grade	NAVAIR Code Number																	
	J1966	SAE 50	12214-04947	211.6	210.24	18.46	18.35	97	96	0	0.06	0.17	0.22	28.48	28.5	<0.005	<0.005			
	J1899	SAE 50	12214-04953	206.5	206.62	20.33	20.22	115	114	0	0	0.21	0.16	28.55	28.5	<0.005	<0.005	275.51	y	4.46
		SAE 50+	12214-04954	180.4	182.49	18.72	18.78	117	116	0	0	0.24	0.15	27.01	27.1	<0.005	<0.005	249.87		4.71
		SAE 60	12214-04955	257.9	257.65	23.47	23.32	113	112	0	0	0.14	0.16	28.17	28.2	<0.005	<0.005	266.36		5.73
		SAE MG1	12214-04956	158	157.21	19.64	19.57	143	143	0	0	0.16	0.13	30.18	30.2	<0.005	<0.005	355.51	y	4.81
		SAE MG2	12214-04957	236.5	238.46	24	24.04	127	126	0	0.04	0.18	0.13	28.93	28.9	<0.005	<0.005	260.37		5.5
N	SAE Standard	Grade	NAVAIR Code Number																	
(Navy)	J1966	SAE 50	12214-04958	229.9	n/a	20.06	n/a	100	n/a	0	n/a	0.3	n/a	28.43	n/a	n/a	n/a			
	J1966	SAE 50	12214-04959	227.6	n/a	19.9	n/a	100	n/a	0	n/a	0.37	n/a	28.08	n/a	n/a	n/a			
	MIL-PRF-6081	1010	12214-04960	9.29	n/a	2.52	n/a	96	n/a	0	n/a	0.01	n/a	29.55	n/a	n/a	n/a	249.89	y	

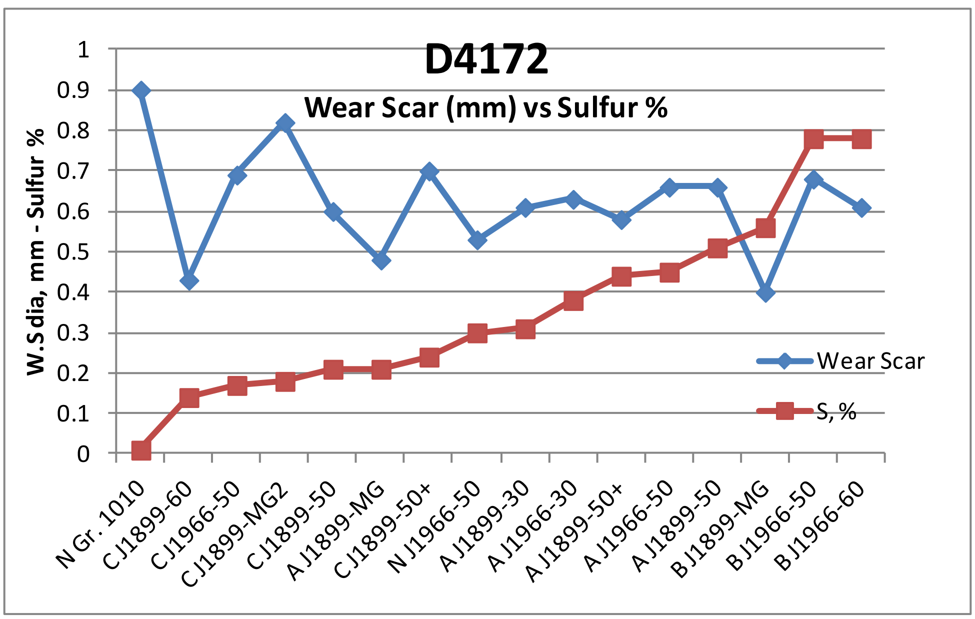
* various methods used

Appendix C
Correlation Analysis of Various Test Results to Sulfur Content

D2272			
Mfgr / Type	minutes	S, % x 100	S, %
N Gr. 1010	132	1	0.01
C J1899-60	106	14	0.14
C J1899-MG1	94	16	0.16
A J1899-MG	487	21	0.21
N J1966 50	189	30	0.3
A J1899-50+	147	44	0.44
A J1966-50	127	51	0.51
B J1899-MG	429	56	0.56
B J1966-50	98	78	0.78

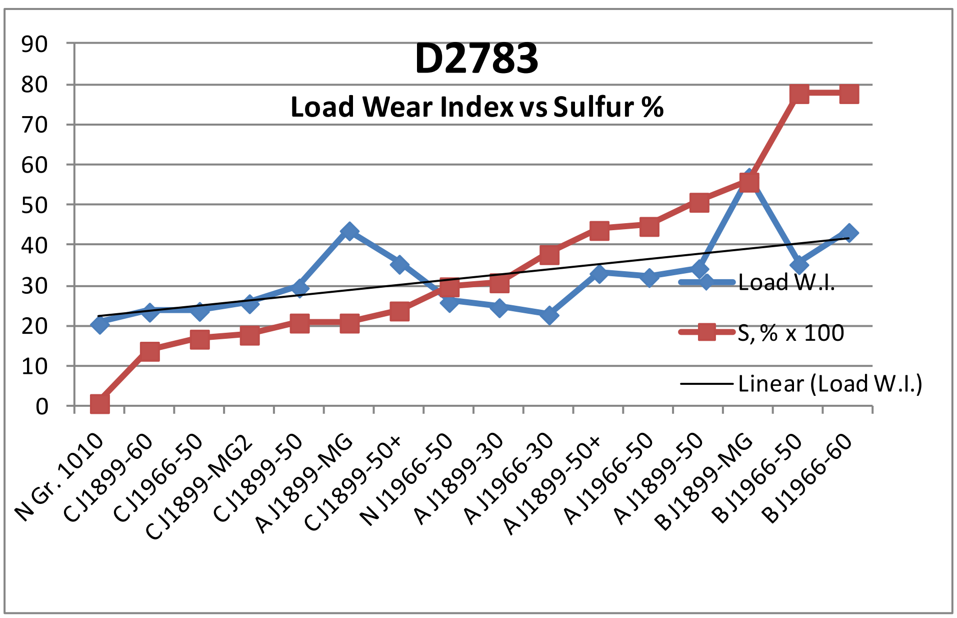


D4172		
Mfgr / Type	Wear Scar	S, %
N Gr. 1010	0.9	0.01
C J1899-60	0.43	0.14
C J1966-50	0.69	0.17
C J1899-MG2	0.82	0.18
C J1899-50	0.6	0.21
A J1899-MG	0.48	0.21
C J1899-50+	0.7	0.24
N J1966-50	0.53	0.3
A J1899-30	0.61	0.31
A J1966-30	0.63	0.38
A J1899-50+	0.58	0.44
A J1966-50	0.66	0.45
A J1899-50	0.66	0.51
B J1899-MG	0.4	0.56
B J1966-50	0.68	0.78
B J1966-60	0.61	0.78

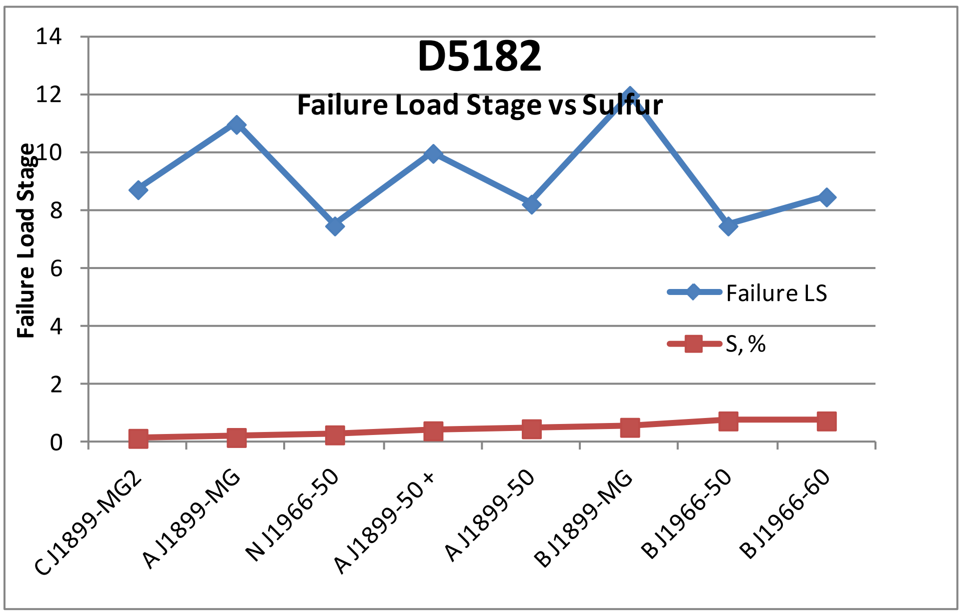


D2783 -Weld Point			
Mfgr / Type	Weld Pt.	S, % x 100	S, %
N Gr. 1010	271.7	1	0.01
C J1899-60	271.7	14	0.14
C J1966-50	250	17	0.17
C J1899-MG2	293.3	18	0.18
C J1899-50	250	21	0.21
A J1899-MG	315	21	0.21
C J1899-50+	250	24	0.24
N J1966-50	250	30	0.3
A J1899-30	250	31	0.31
A J1966-30	250	38	0.38
A J1899-50+	250	44	0.44
A J1966-50	271.7	45	0.45
A J1899-50	250	51	0.51
B J1899-MG	315	56	0.56
B J1966-60	271.7	78	0.78
B J1966-50	315	78	0.78

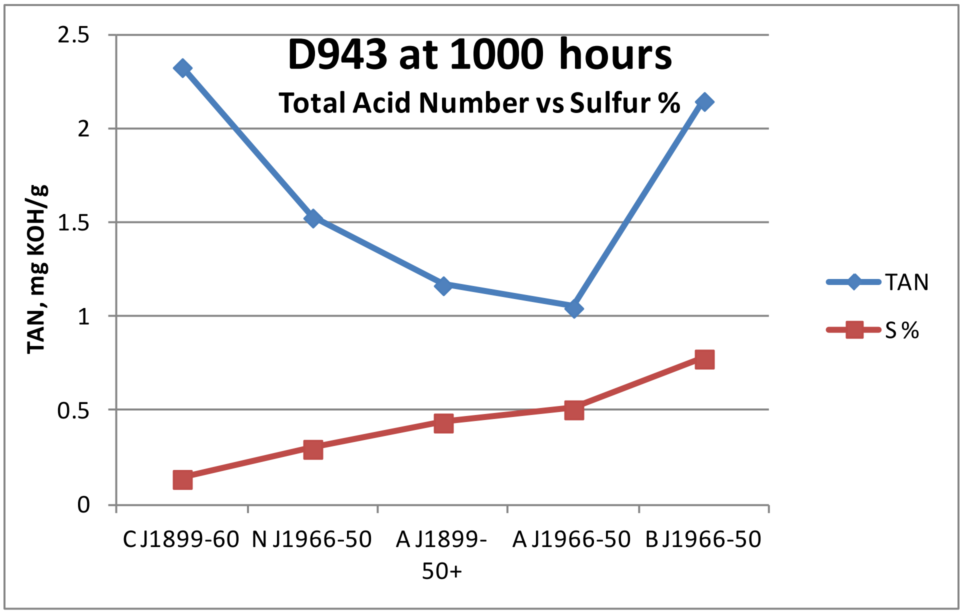
D2783 - Load Wear Index			
Mfgr / Type	Load W.I.	S, % x 100	S, %
N Gr. 1010	20.7	1	0.01
C J1899-60	23.7	14	0.14
C J1966-50	23.9	17	0.17
C J1899-MG2	25.8	18	0.18
C J1899-50	29.7	21	0.21
A J1899-MG	43.9	21	0.21
C J1899-50+	35.6	24	0.24
N J1966-50	26.1	30	0.3
A J1899-30	24.8	31	0.31
A J1966-30	23	38	0.38
A J1899-50+	33.3	44	0.44
A J1966-50	32.3	45	0.45
A J1899-50	34.5	51	0.51
B J1899-MG	57.2	56	0.56
B J1966-50	35.5	78	0.78
B J1966-60	43.5	78	0.78



D5182	Failure Load Stage	
Mfgr / Type	Failure LS	S, %
C J1899-MG2	8.75	0.18
A J1899-MG	11	0.21
N J1966-50	7.5	0.3
A J1899-50 +	10	0.44
A J1899-50	8.25	0.51
B J1899-MG	12	0.56
B J1966-50	7.5	0.78
B J1966-60	8.5	0.78



D943 - TAN at 1004 hours		
Mfgr / Type	TAN	S %
C J1899-60	2.33	0.14
N J1966-50	1.53	0.3
A J1899-50+	1.17	0.44
A J1966-50	1.05	0.51
B J1966-50	2.15	0.78



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
09-30-2013	Technical	01-30-2012 to 07-01-2013

4. TITLE AND SUBTITLE
Development of a New Specification for Aircraft Catapult Lubricant, LA7, NSN9150-01-430-2884

5a. CONTRACT NUMBER N/A
5b. GRANT NUMBER N/A
5c. PROGRAM ELEMENT NUMBER N/A

6. AUTHOR(S)
Shimski, John; Author
Schmidt, Dawn.; Editor
McDonnell, James ; Editor
Mearns, Douglas ; Editor

5d. PROJECT NUMBER N/A
5e. TASK NUMBER N/A
5f. WORK UNIT NUMBER N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Fuels & Lubricants
Cross Functional Team
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Patuxent River, MD 20670

8. PERFORMING ORGANIZATION REPORT NUMBER
NF&LCFT Report 441/13-009

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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NPRE Program
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Patuxent River MD 20670

10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION / AVAILABILITY STATEMENT
A Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT
The steam driven shipboard aircraft catapult systems have traditionally used qualified aviation piston engine oils (APEO's) to lubricate critical parts. The catapult launch systems first used products meeting the old military specifications MIL-L-6082 or MIL-L-22851. In 1995 the military specifications were canceled and replaced with the commercial SAE Standards (J-Spec's), J1966 and J1899. Unfortunately these APEO's are quickly becoming specialty products and are no longer available in bulk quantities which is how they are primarily used in the catapult launch systems. As a result Defense Logistics Agency – Energy (DLA-E) agreed to provide funding for a project to develop a new lubricant specification to address the shipboard aircraft catapult application. The goal of this program was to develop a replacement specification for the LA7 aircraft catapult launch system lubricant that would provide adequate performance and be readily obtainable in bulk quantities by the procurement community. The approach followed in this program was based upon a review of lubrication needs of the catapult systems, the fact the systems have traditionally used qualified aviation piston engine oils (APEO's) and that current APEO's are providing acceptable performance. Samples of current APEO's were obtained from the three primary APEO producers and subjected to a series of standardized, readily available performance tests Analysis of the data collected in this program lead to the development of a proposed set of tests and limits for a Commercial Item Description specification.

15. SUBJECT TERMS
LA7, Aviation Piston Engine Lubricant, Aircraft Steam Catapult Lubricant, Aircraft Piston Engine Oil

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Douglas F. Mearns
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Unclassified Unlimited	58	**19b. TELEPHONE NUMBER** *(include area code)* 301-757-3421